Miocene Diatom Assemblages from the Onnagawa Formation and their Distribution in the Correlative Formations in Northeast Japan

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By

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Contents

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Abstract

This paper describes diatom assemblages from the middle Miocene Onnagawa formation, Oga Peninsula, Akita Prefecture, Northeast Japan, and their distribution in two correlative formations in Akita and Aomori Prefectures, the Yorinobezawa and Owasawa formations, respectively.

From 25 samples from the Onnagawa, three from the Yorinobezawa, and five from the Owasawa, 64 diatom forms were distinguished. They are distributed in 23 genera, and 50 species and varieties were identified, including eight new species.

Besides the samples from the above-mentioned formations of the middle Miocene, five samples from the higher horizons (upper Miocene) were examined to eliminate longer ranged species which might otherwise be chosen as one of the characteristics for the definition of the middle Miocene assemblages.

Frequencies of the species in samples were obtained by a single count of 200 specimens for each sample. With the limits of expectation of these observed frequencies as the guide, the diatom assemblages of the Onnagawa formation, represented by the 25 samples, were analysed with regards to their positions in the stratigraphic sections. As the result it was found that, if the chosen eight species are employed as markers, the distribution of diatoms in the Onnagawa formation can be grouped into three assemblages. They are: *Coscinodiscus Yabei* assemblage, the diatom assemblages A, and C.

The *Coscinodiscus Yabei* assemblage is satisfactorily defined by the high frequencies of the eight marker species, which are themselves paleobotanically peculiar to the Japanese Miocene diatom flora, and by the presence of *Coscinodiscus Yabei* which is restricted to the assemblage.

The application of the same analysis to the Yorinobezawa and Owasawa samples revealed that the defined *Coscinodiscus Yabei* assemblage is also distributed in these middle Miocene formations, leaving assemblage characteristics unchanged. The location of the Owasawa formation is more than 80 km from Oga Peninsula where the Onnagawa formation is distributed.

Acknowledgements

The present writer was initiated into the study of diatoms by Dr. S. Endo, who was then Professor in Paleontology, Institute of Geology and Paleontology, Tohoku University, Sendai. The writer is particularly grateful to Dr. Endo for his suggestion to take up the subject, and his constant guidance and encouragement.

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Introduction

It has been more than fifty years since Brun and Tempère (1889) and Pantocsek (1903) introduced to Science numbers of fossil diatom species from Japanese materials they received. The records of the exceptionally well preserved Japanese flora have become well known among students of diatoms, and formed an important part of the comprehensive illustrated catalogue (Schmidt, 1885–1937), and checklist (De Toni, 1891–94) published in those early years. It was unfortunate, however, that the information given by the above-cited authors concerning the sources of their material was very meagre. Consequently, the stratigraphic application of these classic works, which are undoubtedly of great taxonomical importance, is limited. The detailed studies of fossil diatoms, particularly those from marine deposits, have been since neglected in Japan, until recent papers of Ichikawa (1950) and Okuno (1952) have considerably overcome this deficiency.

Meanwhile, with definite intensions of employing the diatoms for stratigraphic purposes, Hanna, Lohman, Long et al., and Reinhold (see Kanaya, 1957) described these microscopic plants from marine strata of North America and Java, ranging from upper Cretaceous to Pleistocene. The working experience on the upper Eocene assemblages of California, led the present writer to believe, as all these specialist have believed, that diatoms can be employed as successfully for exact stratigraphic correlation as any other categories of fossils if they are carefully identified (Kanaya, 1957).

To utilize diatoms for stratigraphic purposes and to show relationships between the fossil floras of Japan and other Circum-Pacific countries, much more descriptive work must be done in Japan as well as in other countries. It is particularly important to ascertain the extent to which the diatoms are reliable for stratigraphic correlation. The present paper is designed as a further contribution toward making the diatoms of Japan better known, and at the same time it is also designed to serve as an example showing the distribution of diatom assemblages in the stratigraphically correlative strata.

The writer began the study of Japanese diatoms in 1949, with the examination of diatom assemblages found from the Miocene Owasawa formation, Aomori Prefecture, Northeast Japan. He has been concentrating on the description of the fossils excavated from a number of Miocene and Pliocene formations in Northeast Japan by carrying out taxonomic studies, determining relative abundance of species within a given assemblage, and reviewing the geologic and ecologic significance of each species and assemblages. The present report is the first to record one of these investigations, and deals with diatom assemblages from the middle Miocene Onnagawa formation and its correlative, Yorinobezawa in Akita Prefecture, and from the Owasawa formations in Aomori Prefecture in Northeast Japan.

The first chapter of this paper gives information concerning the stratigraphic notes about the formations from which the 38 samples incorporated in the present study were obtained. The samples include, moreover, those from the Onnagawa and its correlatives, also the ones from the higher horizons (upper Miocene) for the comparative studies. The second chapter explains the methods and techniques employed in the present investigation. The analysis and descriptions of diatom assemblages in the Onnagawa formation, and their detection in the cc rrelative formations are given in the thiId chapter. The last chapter of this report is devoted to the systematic description of 64 diatoms distinguished in the samples from the Onnagawa and its correlative Yorinobezawa, and Owasawa formations. Of 64 forms distributed in 23 genera, 50 are specifically determined, including eight new species. Remarks on their geologic as well as ecologic records, mainly checked by using De Toni's checklist as a key, are also given in this chapter under the appropriate species.

CHAPTER I

STRATIGRAPHIC NOTES

The material incorporated in the present study includes:

1. twenty-five samples from the Onnagawa formation, in the Hirasawa, and Shinzan areas of Oga Peninsula, Akita Prefecture;
2. three samples from the Yorinobezawa area, south of Yonaizawa, Akita Prefecture;
3. five samples from the Owasawa formation, in the area south of Hirosaki City, Aomori Prefecture; and
4. five samples from the strata of higher horizons (upper Miocene in the present paper) developed along the eastern and western borders of the Hirosaki Basin, Aomori Prefecture.

The following notes describe the localities and stratigraphic positions of the samples as well as to give brief outlines of the stratigraphy of the areas and of the correlation adopted in the present study.

Oga Peninsula, Akita Prefecture

Stratigraphy

The stratigraphic classifications of the Miocene and Pliocene strata of Oga Peninsula are shown on the correlation table (Table 1). The classification first established by Toyama (1925) has been widely accepted by Japanese geologists as a standard with which the Miocene and Pliocene formations along the Japan Sea coast are correlated, except that of the strata lower than the Nishikurosawa formation. The strata lower than the Nishikurosawa formation have recently been extensively studied by a group of stratigraphers[1] who are interested in pyroclastic rocks distributing in the steep western coast of the peninsula, which Toyama grouped as Honzan volcanics The result, which itself deserves one chapter, is however, not mentioned here, except those having close bearing on the present discussion.

From thin laminated mudstone intercalated within tuffaceous sandstone in the trachy-andesitic lower part of the Monzen formation (Huzioka et al., 1954, p. 6), Huzioka and Inoue (1952, p. 361) found the plant assemblage of Monzen locality which, being characterized by yielding *Metasequia japonica* (Endo), *Tsuga*

1) Kano and Takayasu (1955); Huzioka et al. (1954); Miyagi and Uruno (1956); Miyagi (1955, 1958).

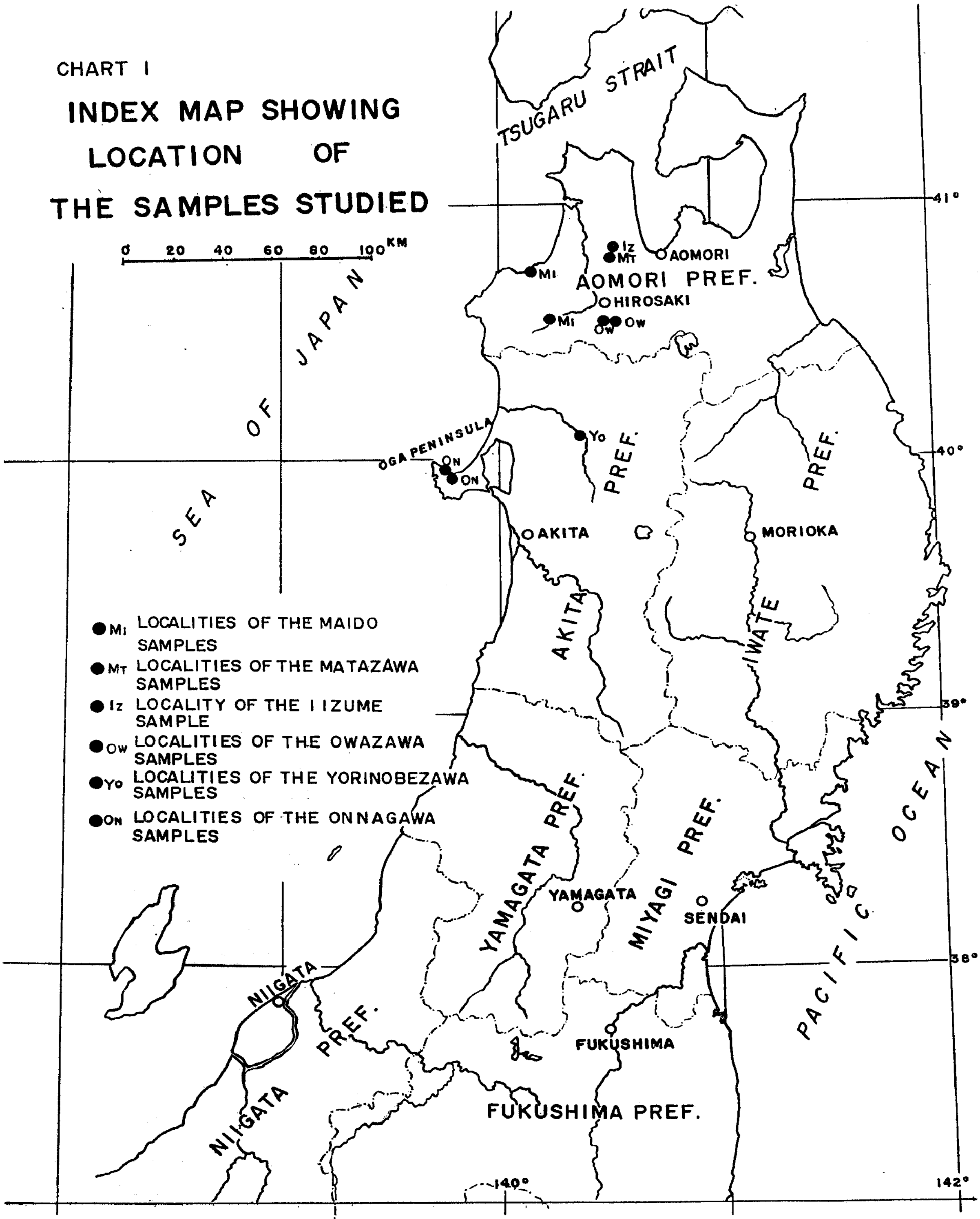


CHART I
INDEX MAP SHOWING LOCATION OF THE SAMPLES STUDIED
0 20 40 60 80 100 KM
TSUGARU STRAIT
AOMORI
AOMORI PREF.
HIROSAKI
SEA OF JAPAN
OGA PENINSULA
AKITA
AKITA PREF.
MORIOKA
IWATE PREF.
YAMAGATA PREF.
YAMAGATA
MIYAGI PREF.
SENDAI
PACIFIC OCEAN
NIIGATA
NIIGATA PREF.
FUKUSHIMA
FUKUSHIMA PREF.
41°
40°
39°
38°
140°
142°
Mi LOCALITIES OF THE MAIDO SAMPLES
Mt LOCALITIES OF THE MATAZAWA SAMPLES
Iz LOCALITY OF THE IIZUME SAMPLE
Ow LOCALITIES OF THE OWAZAWA SAMPLES
Yo LOCALITIES OF THE YORINOBEZAWA SAMPLES
On LOCALITIES OF THE ONNAGAWA SAMPLES

Review of the stratigraphic classification of Tertiary formations of Oga Peninsula, and correlation of the Miocene and Pliocene formations in Akita and Aomori Prefectures

TABLE 1

OGA PENINSULA: TOYAMA (1925)		OHASHI (1930)	HUZIOKA (1950) HUZIOKA et al. (1954)			MIYAGI (1958)	HANZAWA (1954)			KANAYA (PRESENT STUDY)	TIME-STRATIGRAPHIC FRAMEWORK ADOPTED: 3	1	2
SHIBIKAWA SAND	PLIOCENE	SHIBIKAWA SAND			SHIBIKAWA F. 70 M.		EARLY PLIOCENE		SHIBIKAWA F.	SHIBIKAWA F.	PLIOCENE		P
WAKIMOTO SANDY SHALE	PLIOCENE	WAKIMOTO SANDY SHALE		FUNAKAWA GROUP	WAKIMOTO F. 500-600 M.		EARLY PLIOCENE		WAKIMOTO F.	WAKIMOTO F.	PLIOCENE	VI	P
KITAURA ALTERNATION	MIOCENE	KITAURA ALTERNATION	MEDIAL TO LATE MIOCENE (F3 G.)	FUNAKAWA GROUP	KITAURA F. 500-600 M.			OGASHIMA GROUP	KITAURA F.	KITAURA F.	UP. MIOCENE	V	K
FUNAKAWA BLACK SHALE	MIOCENE	FUNAKAWA BLACK SHALE; NOMURA GREY SHALE; HIRASAWA TUFF	MEDIAL TO LATE MIOCENE (F3 G.)	FUNAKAWA GROUP	FUNAKAWA F. 550-650 M.			OGASHIMA GROUP	FUNAKAWA F.	FUNAKAWA F.	UP. MIOCENE	IV	F
FUNAKAWA BLACK SHALE	MIOCENE	FUNAKAWA BLACK SHALE; NOMURA GREY SHALE; HIRASAWA TUFF	MEDIAL TO LATE MIOCENE (F3 G.)	FUNAKAWA GROUP	MINAMIHIRASAWA F. 65 M.			OGASHIMA GROUP	FUNAKAWA F.	MINAMIHIRASAWA F.	UP. MIOCENE	III	F
ONNAGAWA SILICEOUS SHALE	MIOCENE	DIATOM EARTH; ONNAGAWA SILICEOUS SHALE	MEDIAL TO LATE MIOCENE (F3 G.)	FUNAKAWA GROUP	ONNAGAWA F. 190 M.			OGASHIMA GROUP	ONNAGAWA F.	● SHINZAN DIAT.M.; ONNAGAWA F.; HIRASAWA DIAT.M. ●	MID. MIOCENE	III	O
NISHI-KUROSAWA F.; DAIJIMA F.	MIOCENE	NISHI-KUROSAWA F.; DAIJIMA F.	M. MIOCENE (F2)	DAIJIMA GROUP	NISHIKUROSAWA F. 150 M; DAIJIMA F. 500 M; BUTAIJIMA CGL.	DAIJIMA F.: NAKAYAMATOGE CGL.; SHIOSESAKI CGL.	HELVET	OGASHIMA GROUP	NISHIKUROSAWA F.; DAIJIMA F.; TSUBAKI CGL.	NISHIKUROSAWA F.	MID. MIOCENE	II	PO
HONZAN VOLCANICS	PALEOGENE	SUGOROKU PYROCLASTS	EARLY MIOCENE	MONZEN GROUP	MONZEN F		BURDIGAR.		SUGOROKU GROUP			I	
HONZAN VOLCANICS	PALEOGENE	SUGOROKU PYROCLASTS	EARLY MIOCENE	MONZEN GROUP	AKASHIMA F.	NISHIOGA GROUP	OLIGOCENE		NISHIOGA GROUP			I	
	PALEOGENE				NYŪDŌZAKI IGNEOUS ROCKS	NISHIOGA GROUP	OLIGOCENE		NISHIOGA GROUP				

TIME-STRATIGRAPHIC FRAMEWORK ADOPTED: 3	1	2	AKITA OIL FIELD: J. IKEBE (1957)	ANIAI: SAITO & OSAWA (1956)		TAKANOSU-YONAISAWA: IMAIZUMI & KOTAKA (1952)		AJIGASAWA: KITAMURA (1957)	HIROSAKI BASIN, WESTERN MARGIN: IMANISHI (1949)	HIROSAKI BASIN, SOUTHERN MARGIN: KANAYA (1949)	HIROSAKI BASIN, EASTERN MARGIN: IMAIZUMI (1949)
PLIOCENE		P	SHIBIKAWA F.				MITSUKITA F.				
PLIOCENE	VI	P	TOFUIWA F.; SASAOKA F.			OCHIAI GROUP	YUKITAZAWA F.	NARUSAWA F.			
UP. MIOCENE	V	K	TENTOKUJI F.; KATSURANE F.			OCHIAI GROUP	KOSAWADA F.; HANEYAMA F.	MAIDO F.	MAIDO F. ● 500 M.	MISSING	MATAZAWA F. ● 50-100 M.
UP. MIOCENE	IV	F	FUNAKAWA F.			BUSSHAZAWA GROUP	KAMIKOAMI F.	AKAISHI F.	AKAISHI F. 500 M.	NISHIMEYA F 500 M.	IIZUME F. ● 100-550 M.
UP. MIOCENE	III	F				BUSSHAZAWA GROUP	OTAI F.	AKAISHI F.	AKAISHI F. 500 M.	NISHIMEYA F 500 M.	IIZUME F. ● 100-550 M.
MID. MIOCENE	III	O	ONNAGAWA F.	ONNAGAWA F.		BUSSHAZAWA GROUP	YORINOBE-ZAWA F. ●	ŌDŌJI F.	KOMORI F. 150 M.	OWASAWA F. ● 600 M.	ITADOME F. 100-200 M.
MID. MIOCENE	II	PO		ANIAI F.	SHALE; SST. & TF.; CONGLOMERATE; COAL BERING SH; LOWER DOLERITE		FUNAGI F.; OKUMINAIZAWA F.	TANOSAWA F.	MAENOKAWA F.	AINAIGAWA F. 300-700 M	
	I						? USHIZAWA F.				

Explanation

1: the stages proposed by Kitamura (1958a)
2: the molluscan zones proposed by Kotaka (1957, 1958)
3: assumed geologic ages of the provinc ialunits

Miogypsina-Operculina foraminifer fauna
the "pre-O" pecten fauna of Kotaka
the "Daijima-type" flora
the "Aniai-type" flora
● formations yielding the diatomaceous rocks studied

diversifolia Mast., *Picea Kanoi* Huzioka (M.S.,) *Picea ugoana* Huzioka (M.S.), *Carpinus subjedoensis* Konno and *Betula* sp., was said to indicates its "Aniai flora" aspect. According to Huzioka (1949, p. 177) the Aniai flora has a similarity, in composition, with the living community along the southern wood-line of the temperate reciduous forest.[2] The strata bearing the fossil plants was called the Kohama formation by Hanzawa, as unit of the Sugcroku group in his new sense (1954, p. 197), which overlies his Nishioga group with a clino-unconformity. Huzioka and Inoue distinguished this Kohama plant fossils (Hanzawa, 1954, p. 197) from that of the Daijima formation which is well known for the "Daijima flora" carrying such characteristic species as *Liquidambar formosana* Hance and *"Comptoniphyllum" Naumanni* (Nathorst), and indicates warm humid climate of the coastal region (Huzioka, 1949, ibid.[3]).

Stratigraphic relation of the strata containing the two assemblages varies by authors ; Hanzawa (1954, p. 200) considered that the Sugoroku group (new sense) containing the Kohama formation is overlain conformably by basal conglomerate of the Daijima formation; Kitamura (1958a, p. 2) believed that Monzen yielding the Kohama assemblage is overlain unconformably by the Daijima, though the time break was insignificant; and Huzioka, in his latest publication concerning the matter, wrote that the relation is not ascertained at the field due to faults (Huzioka, *et al.*, 1954, p. 12).

Recently, Miyagi (1858, p. 196), expressed his view concerning this part of the stratigraphic sequence. He extended the Daijima formation downward to include the Sugoroku group of Hanzawa, and agreed with Hanzawa to consider that the strata bearing two plant assemblages are conformable. The Monzen conglomerate which Hanzawa considered the basal conglomerate of his Sugoroku group is Miyagi's Shiosesaki conglomerate and tuff member, which Miyagi considered the basal conglomerate of the Daijima formation of the extended sense. According to Miyagi the laminated mudstone from which Huzioka and Inoue found the plant assemblage of Monzen locality (which Hanzawa called the Kohama fossil plants) was not the intercalation of the tuffaceous sandstone in the trachytic andesite, but of the Shiosesaki conglomerate, which unconformably overlies the Nishioga group (of Hanzawa, 1954), and in the Nishioga group both Hanzawa and Miyagi include the

2) According to Tanai (1955, p. 3), "The Aniai-type flora is most similar to the present flora which are now distributed from central to northern China. And yet, considering from the associated conditions indicated by the flora, it is most predominant in the elements of mountain-slope."

3) According to Tanai (*ibid.*), "The present equivalents of the Daishima-type species are living mostly in the subtropical or warm region, and scarcely in the temperate or cold region. Among the living flora of East Asia, the Daishima-type flora is considered to be closely similar to the present flora of Formosa, or from central to southern China. And it is dominant in the lowland elements near the coast."

trachytic andesite of the Monzen formation of Huzioka and others (Huzioka, *et al.*, 1954). Kitamura is in favour of this view[4] over his previous understanding (1958a, *l. c.*).

Thus with the Shiosesaki conglomerate (=Monzen conglomerate of Hanzawa, 1954) at its base, the Daijima formation in the new sense added five members (totalled appr. 250 m) to the Daijima formation with the "Daijima flora" of the earliar writers (*e. g.* Huzioka, 1950) to which Miyagi's uppermost member, the Nakayama-toge sandstone and conglomerate member (40–60 m thick) corresponds. The Kohama fossil plants (of Hanzawa, 1954, the assemblage of Monzen locality of Huzioka and Inoue, 1952) is conformably lower than the well known locality of the Daijima flora, and between two horizons of the different floral type, there comes another assemblage bearing the Daijima floral aspect which was also mentioned by Huzioka and Inoue (1952, *l. c.*) as of the Sugoroku locality when they reported that of the Monzen locality. According to them the lower two horizons are separated by a thickness of approximately 60 m.

The Daijima formation of the earlier sense (and the Nakayama-toge sandstone and conglomerate member of Miyagi) which starts from the basal conglomerate at its base (Tsubaki conglomerate of Hanzawa, 1954), is mostly composed of poorly sorted sandstone and conglomerate with tuffaceous mudstone containing the Daijima flora.

More than 20 species of marine molluscs were also found by Kotaka in the muddy facies of the formation (Huzioka *et al.*, 1954, p. 10), but its actual position in the formation was hardly determinable, except that the rocks also contained plant fragments, according to Kotaka.[5]

The Nishikurosawa formation attains approximately 150 m thick at the southern coast of the peninsula where the formation conformably overlies the terrestrial to deltaic Daijima formation with gradual transition. The formation is much thinner in its type area, Nishikurosawa-Hirasawa area at the northern coast, where the formation yields such characteristic Orbitoid Foraminifera as *Miogypsina kotoi* Hanzawa, *Operculina complanata* Defr. *japonica* Hanzawa, *Amphistegina lessoni* d'Orb., (Hanzawa, 1935) as well as an echinoid, *Astriclypeus manni* Verill *ambigenus* Nisiyama (Nisiyama, 1945,) and some pectinids. In the type area, the Nishikurosawa is said to overlie unconformably with basal conglomerate the trachytic andesite of the Nishioga group (as of the Monzen formation, according to Huzioka *et al.*, 1954, p. 15). The distribution of the pre-Nishikurosawa rocks limited the horizontally lain Nishikurosawa to distribute in a restricted area, having about 1600 m in east-west width and extends in the equal distance southwardly from the shore.

4) Oral communication, November, 1958.
5) Oral communication, November, 1958.

The writer failed to observe its basal contact at exposures along the coast where greenish-grey tuffaceous sandstone with woody fragments, developing in the western part, is the exposed base. The contact with the Omotsuzaki andesite at the east was observed to be a fault relation.

The section shown in colums 2 of Chart 2 starts at immediately above the tuffaceous sandstone. As are shown in the section, the strata consist of, in ascending order, calcareous conglomeratic sandstone; glauconite-bearing green fine-medium grained sandstone; glauconite-bearing granule conglomeratic sandstone; greenish grey fine-medium grained sandstone exposed along the cliff; granule-pebble congomeratic sandstone; and finally a thin layer of tuffaceous medium-fine grained sandstone which at loc. no. Ak-44 underlies an alternation of glauconitic black flinty shale, and mudstone which is also glauconitic.

The thickness below this glauconitic alternation totalled approximately 12 m from the calcareous conglomeratic sandstone containing the before-mentioned *Miogypsina-Operculina* fauna.

The alternation of glauconitic flinty shale and glauconitic clayey mudstone, which is sometimes represented entirely by flinty shale, attains approximately 2 m thick and is persistent in the localities around Hirasawa village (see Chart 2, sections 1–4). The layer is succeeded ascendingly by fine clastics varying from fine-grained sandstone to clayey mudstone, which are mostly diatomaceous, partly glauconitic, and intercalate a few thin layers of flinty shale.

The criteria to set the upper limit of the Nishikurosawa formation has been different by authors. Toyama (1925) who first proposed the Nishikurosawa formation considered the "shale facies" as the upper part of the formation. His map indicates that he included the diatomaceous part with the Nishikurosawa, though nothing was mentioned about its being diatomaceous. Huzioka (Huzioka, *et al.*, 1954, p. 16) who now limits the Nishikurosawa formation at the Hirasawa localities to the strata below the glauconitic flinty shale, and hard mudstone, once followed Toyama in this respect, though he noticed then the part above the flinty shale is diatomaceous (Huzioka, 1950, p. 16).

Hanzawa (1954) placed the boundary at the same horizon, and both Hanzawa and Huzioka considered the strata thus separated from the Nishikurosawa as of the Onnagawa formation, which consists mainly of siliceous or porcellaneous hard shales and mudstone, and conformably overlies the Nishikurosawa elsewhere in the peninsula.

From similarities in lithology and order of succession, the view presented by Hanzawa and Huzioka seems to be justified, although the strata in the Hirasawa area can not be traced in the field to the main body of the Onnagawa formation, due to a fault at the east of the Hirasawa area.

The present writer calls the diatomaceous mudstone and the associated glauconitic shales showing an isolated distribution in the Hirasawa area the Hirasawa diatomaceous mudstone member of the Onnagawa formation, taking the exposures around the Hirasawa village as the type. The member includes the diatomaceous mudstone and the glauconitic shaly rocks underlying the diatomaceous strata. The maximum thickness obtained for the member was 9 m, and being exposed in nearly horizontal, its top is cut by terrace deposits. The glauconitic shaly layer at the base, which serves as a key bed in tracing diatomaceous part in the exposures around Hirasawa village is not necessarily persistent in the area south of the village. For examples, at IGPS loc. no. Ak-47, (Chart 2, sec. 6) which is about 1000 m south of Hirasawa village, the diatomaceous mudstone occurs below a thin layer of the glauconitic flinty shales and above a glauconitic fine grained sandstone which marks the base of the member here; and at IGPS loc. no. Ak-49 (Chart 2, sec. 5) which is the southernmost exposure of the Nishikurosawa and the Hirasawa diatomaceous mudstone member in the Hirasawa area, there is no such glauconitic shaly layers through an obtained thickness of 8 m above, the hard medium-coarse grained sandstone which, by definition, is of the Nishikurosawa formation. Even in these localities, the upper boundary of the underlying Nishikurosawa formation is easy to draw at the top of the coarser clastics, usually represented by medium to coarse grained sandstone, either conglomeratic or not.

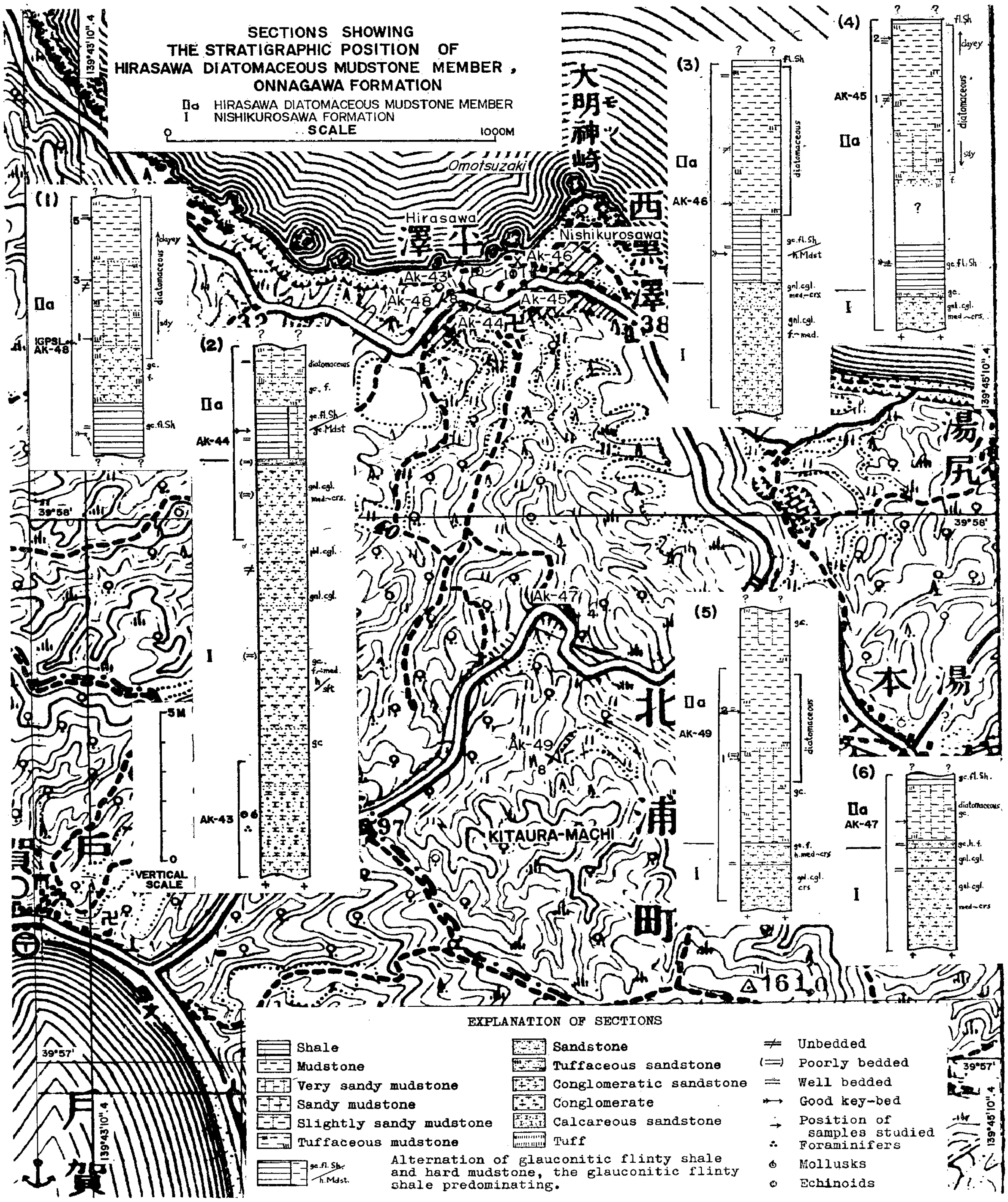
Nine samples collected from five localities are incorporated in the present study to represent the diatom assemblages of the Hirasawa diatomaceous mudstone member of the Onnagawa formation. Their localities are listed under another heading.

The main body of the Onnagawa formation extends northwest, from its type locality on the south coast of the peninsula to the Shinzan area, about 3 km south of Kitaura-machi on the north coast. From the Hirasawa area mentioned, the Shinzan area is about 5 km southeast, and between the two areas, there is a fault (the Minamihirasawa fault of Huzioka, 1950) which, running with NNW trend, makes direct tracing of the strata in two areas impossible.

The Onnagawa formation attains 195 m in thickness (Huzioka, 1950, p. 8) at its type section along the south coast of the peninsula, where the formation conformably overlies the Nishikurosawa. Huzioka placed the base of the Onnagawa formation at the layer of glauconitic sandstone, which is approximately 50 m above the 15 m thick calcareous tuffaceous sandstone bearing the sponge, *Aphrocallistes* sp. The calcareous sandstone also contains *Ostrea* fragments. It was the mudstone lower than this horizon from which fragmental remains of marine molluscs[6] were found. The part above the *Aphrocallistes* bearing rock is dark grey mudstone which can hardly be distinguished from that of the lower horizons, except

6) Oral communication from Mr. T. Kotaka, November, 1958.

Chart 2

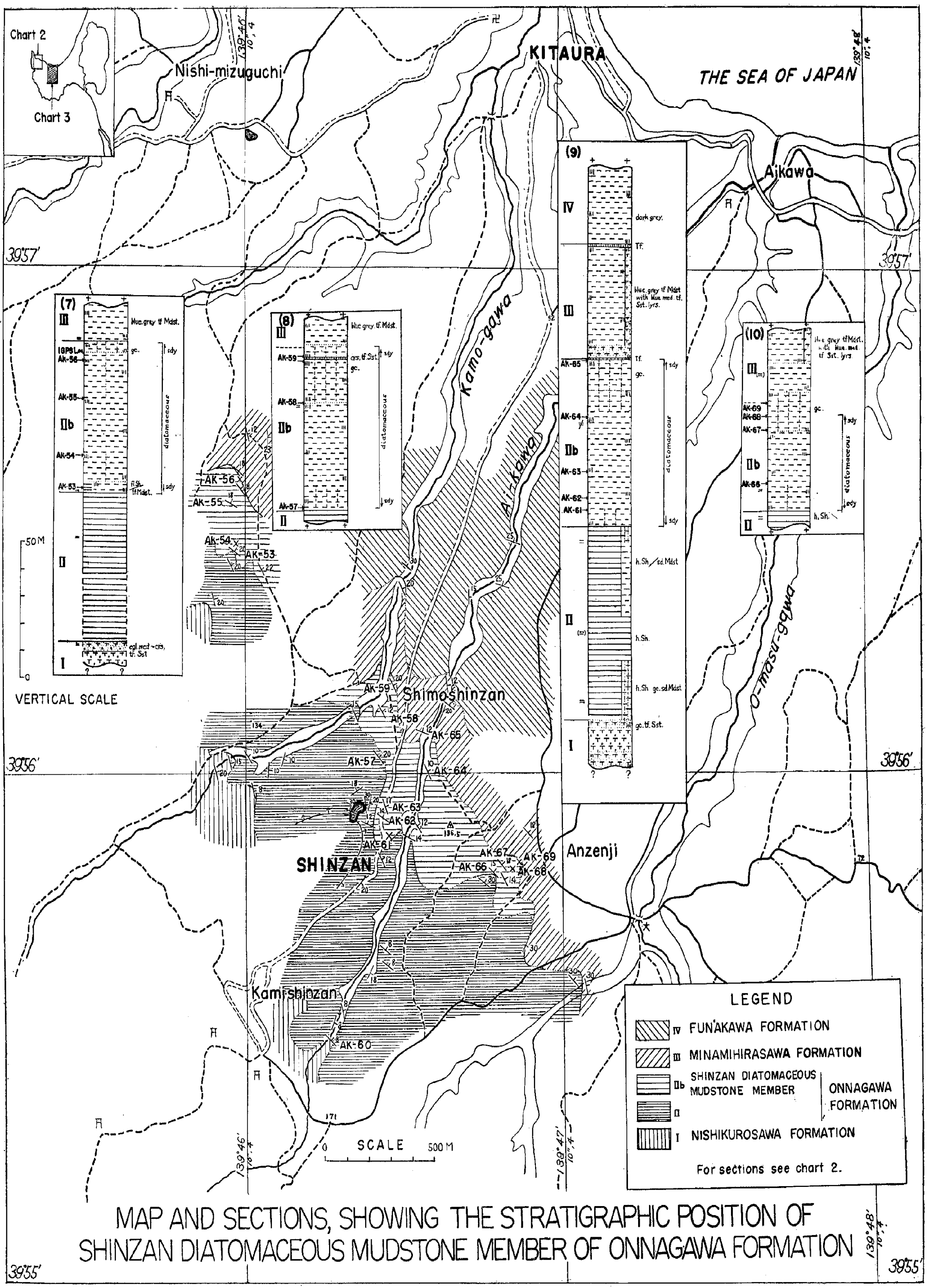

SECTIONS SHOWING
THE STRATIGRAPHIC POSITION OF
HIRASAWA DIATOMACEOUS MUDSTONE MEMBER,
ONNAGAWA FORMATION
IIa HIRASAWA DIATOMACEOUS MUDSTONE MEMBER
I NISHIKUROSAWA FORMATION
SCALE
1000M
Omotsuzaki
Hirasawa
Nishikurosawa
KITAURA-MACHI
VERTICAL SCALE
EXPLANATION OF SECTIONS
Shale
Mudstone
Very sandy mudstone
Sandy mudstone
Slightly sandy mudstone
Tuffaceous mudstone
Alternation of glauconitic flinty shale and hard mudstone, the glauconitic flinty shale predominating.
Sandstone
Tuffaceous sandstone
Conglomeratic sandstone
Conglomerate
Calcareous sandstone
Tuff
Unbedded
Poorly bedded
Well bedded
Good key-bed
Position of samples studied
Foraminifers
Mollusks
Echinoids

that the former is harder, darker in colour, and lacks so far molluscan remains. Above the glauconitic sandstone, (that is : in the Onnagawa formation), mudstone becomes still harder, porcellaneous of siliceous, sometimes flinty, better stratified, and bears marl concretions : all of which are the characteristics of the Onnagawa formation of the type locality.

No mudstone which qualifies to be called diatomaceous were found throughout this section which covers, as is described, the upper part of the Nishikurosawa and entire part of the Onnagawa formation. The porcellaneous and siliceous nature of these rocks may suggest that the condition might has been favourable to disolve opal of diatom values once deposited and to reprecipitate it near by to form denser and more stable siliceous rocks as was suggested by Bramlette (1946, p. 54). Further examination of marl nodules may provide us with well preserved diatom assemblages from this part of the section.

In the Shinzan area, which is approximately 9 km northwest from the type locality of the Onnagawa formation, there is a thckness which chiefly consists of porcellaneous shale. Because that the shale is traced from the type locality of the Onnagawa, the strata have been called the Onnagawa formation, including diatomaceous mudstone which comes above the procellaneous shale and below the Minamihirasawa formation. Since the Minamihirasawa here is an extension of that overlies the Onnagawa at the type locality, the inclusion is justified stratigraphically, though such a diatomaceous strata are lacking in the Onnagawa at its typical sequence. Thus the Onnagawa formation in the Shinzan area is divided into two parts : the lower part (50–80 m thick) is dark grey porcellaneous shale, frequently alternate with sandy mudstone which is sometimes glauconitic, and the upper part (60–0 m thick) is diatomaceous mudstone here called the Shinzan diatomaceous mudstone member, which was once called by Ohashi (1930, p. 746) "De", referring diatom earth.

The sequence which underlies the formation here is also different from that at the type area. Of two localities showing the lower boundary at one locality (see Chart 3, sec. 9) porcellaneous shale with glauconitic sandy mudstone overlies the layers of glauconitic sandstone and sandy mudstone (2 m in total thickness), which is conformably underlain by pebble conglomerate of 6 m thick cemented by medium to coarse grained tuffaceous sandstone. At an other locality (see Chart 3, sec. 7), pebble conglomeratic tuffaceous coarse grained sandstone underlies porcellaneous shale, though the exact boundary was not seen. At both localities, the strata coming below the conglomeratic rocks are tuffaceous medium-coarse grained sandstone, which yields marine molluscan remains found by Kotaka (in Huzioka, et al., 1954, p. 14). The presence of the following pectinids indicates that this is the assemblage of Kotaka's pre-O fauna, and referable to that of the


THE SEA OF JAPAN
KITAURA
Nishi-mizuguchi
Aikawa
Kamo-gawa
Ai-kawa
O-masu-gawa
Shimoshinzan
SHINZAN
Kamishinzan
Anzenji
Chart 2
Chart 3
VERTICAL SCALE
50M
SCALE 500M
LEGEND
IV FUNAKAWA FORMATION
III MINAMIHIRASAWA FORMATION
IIb SHINZAN DIATOMACEOUS MUDSTONE MEMBER
II
ONNAGAWA FORMATION
I NISHIKUROSAWA FORMATION
For sections see chart 2.
MAP AND SECTIONS, SHOWING THE STRATIGRAPHIC POSITION OF SHINZAN DIATOMACEOUS MUDSTONE MEMBER OF ONNAGAWA FORMATION

type locality of the Nishikurosawa formation[7] which, as mentioned previously occurs with *Miogypsina-Operculina* Orbitoid foraminifera fauna.

The pectinids are: *Chlamys kaneharai* (Yokoyama), *Chlamys notoensis* (Yokoyama), *Swiftopecten swifti* (Bernardi), *Patinopecten* cfr. *kagamianus* (Yokoyama), *Patinopecten paraplebejus* Nomura and Hatai, *Placopecten* cfr. *akihoensis* (Matsumoto). Accordingly, the writer considers that the strata underlying the Onnagawa formation in the Shinzan area is the extension of the Nishikurosawa formation in the Hirasawa area, from which the area is separated by a fault, and draws the boundary with the overlying Onnagawa formation at the base of the glauconitic layers of sandstone and sandy mudstone.

The sections given in Chart 3 are arranged taking the lower boundary of the Shinzan diatomite mudstone member at a same line. The middle part of the strata may quality to be called diatomite, but the lower and upper parts are more argillaceous, and more sandy. Glauconite grains contained in the upper part are responsible to make that part sandy.

The upper boundary of the Hirasawa diatomaceous member of the Onnagawa formation with the overlying Minamihirasawa (Huzioka, 1950) is drawn at the top of the diatomaceous part. Huzioka includes diatomaceous glauconitic "tuffaceous sandstone" with his Minamihirasawa formation, because of its glauconitic nature, but the writer places more emphasis on it being diatomaceous, as it is the subject of the present study. The Minamihirasawa formation thus restricted, attains 50 m in thickness in this area, and characterized, as Huzioka remarked, by bluish-grey tuffaceous mudstone intercalating layers of blue medium-grained well sorted tuffaceous sandstone, 20–60 cm in thickness. In the eastern part of the Shinzan area where the diatomaceous member is lacking, the Minamihirasawa directly overlies the hard porcellaneous shale of the Onnagawa formation conformably (Chart 3).

Thus, the Onnagawa formation of the Shinzan area carries in its upper part the Shinzan diatomaceous mudstone member which is lenticular in nature, and below that is the porcellaneous shale which attains 50–80 m in thickness until the underlying Nishikurosawa. This is quite different from the occurrence observed for the Hirasawa diatomaceous mudstone member of the Hirasawa area, which directly overlies the Nishikurosawa with the glauconitic shaly layer of 2 m thick.

As it will be mentioned later, the Shinzan diatomaceous member is divided into two from the diatom assemblages contained, and the lower assemblage (*Coscinodiscus Yabei* assemblage) is distributed also in the Hirasawa diatomaceous member.

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7) Oral communication from Mr. T. Kotaka, November, 1958.

Two alternatives seem to be possible for explanation.

(1) The two diatomaceous mudstones were originally of the same horizon, and it was the shale body of the Onnagawa formation which diminishes its thickness toward the Hirasawa area.

(2) The two diatomaceous members are different in horizon, one at the base, the other at the top of the Onnagawa formation. This means that the diatom flora characterizing the lower diatomaceous member has kept its assemblage characteristics unchanged through a considerable time during which a thickness of 80 m of argillaceous rocks have accumulated.

The available data are, however, not tangeble to determine the one which should be more probable. Although it is rather discouraging, the writer tentatively takes the latter explanation as of the present case, until the lower boundary of the *Coscinodiscus Yabei* assemblage, which is set by a lithological control in the present case, will be ascertained in a continuous diatomaceous sequence. Sixteen samples from 15 localities of the Shinzan diatomaceous mudstone member are incorporated in the present study. Their localities will be found under another heading.

The Minamihirasawa formation is overlain by the Funakawa formation with gradual transition. In the Shinzan area the writer placed the lower boundary of the Funakawa at where white fine grained tuff of 80 cm thick appears. The blue sandstone layers, which are characteristic to the Minamihirasawa formation below, disappear at the boundary, and instead, thin white tuff layers are often intercalated in the tuffaceous mudstone of the Funakawa formation.

The Funakawa is known for its dark coloured massive mudstone intercalating thin tuff layers. It is 650 m in thickness at the type locality of the south coast; becomes thinner towards northwest, 600 m in the central part of the peninsula; and 500 m at the north coast, where the formation was once called by Ohashi as the Nomura grey shale, because the mudstones are in lighter colour (Ohashi, 1930).

The Funakawa formation is conformably overlain by the Kitaura formation, which consists of a regular alternation of sandstone and mudstone layers. Total thickness of the Kitaura has been measured (Huzioka, 1950) to be 600 m in the central part of the peninsula where the formation attains its maximum thickness.

The alternation of the Kitaura formation which grades upward into massive sandy rocks has been called the Wakimoto formation. The Wakimoto is composed of sandy mudstone, muddy sandstone, and sandstone, totaling 350 m in thickness (Huzioka, 1950, p. 10).

The continuous marine record from the Nishikurosawa upward is first interrupted at the top of the Wakimoto formation where the Wakimoto is overlain unconformably by the Shibikawa formation.

The continuous sequence of these fine clastic rocks amount in thickness to more than 1600 m, ranging from medial Miocene to early Pliocene as will be mentioned later. Because that the sequence is continuous, its subdivision serves as the standard to which the Miocene and Pliocene strata of the Japan Sea coast are correlated.

Besides those which are mentioned in previous lines, their fossil records are as follows :

Onnagawa formation : almost barren of molluscan remains, except, rare occurrences of *Thyasira*, *Nuculana*, and *Acila* (Huzioka, et. al., 1954) : foraminifers are rare; and known to contain fish-scales, and fossil fish (Huzioka, et. al., *ibid.*).

Minamihirasawa formation : known to contain smaller foıaminifera of the genera *Cyclammina*, and *Martinottiella* : rarely with fish scales ; a sponge, *Makiyama* is common.

Funakawa formation : known to contain smaller foraminifera among which *Cyclammina japonica* is important. *Makiyama* is also contained. *Solemya* was recorded (Huzioka *et al.*, 1954) from this formation.

Kitaura formation : *Makiyama* is common throughout the formation ; *Nuculana* sp., *Yoldia* sp., *Acila* sp. and *Macoma* sp. were found for mollusks (Huzioka et. al., 1954); smaller foraminifers are common enough to recognize foraminiferal zones (Huzioka et. al., 1954), and the occurrence of *Cyclammina japonica* up to a little above the base of the Kitaura formation (Asano, 1951, p. 19) is important, because this has been one of the reasons to include the Kitaura formation into the Miocene Series.

Wakimoto formation : the formation is known to aontain numerous molluscan fossils (Yabe and Hatai, 1941) as well as smaller foramanifera (Asano, 1939, 1948), by which it has been assigned to be of the early Pliocene in age.

The present paper is the first to study the diatoms in this sequence into considerable detail. The rocks diatomaceous enough for the present study were so far found from the two distomaceous members of the Onnagawa formation. Funakawa formation has often been cited as of diatomaceous, because large *Coscinodiscus* and Radiolaria are sometimes found among foraminifers separated, by sieving, from 50 or 100 grams of mudstone, which does not look particularly diatomaceous. Diatom values contained in such a small quantity are beyond the scope of the present study. (see Chapter II, Preparation of Slides, and also Chapter III, Paleoecological Interpretations).

Remarks on the geologic ages of the diatomaceous rocks incorporated in the present study

To make the Japanese records of diatom species to be comparable with those from other parts of the world, their geologic ages should be given by the terminology reasonably defined.

Several approaches (*e. g.* Makiyama, 1939: Ikebe, 1954; Kitamura, 1958a) have been made by Japanese stratigraphers and paleontologist to establish for the Tertiary System of Japan a time-stratigraphic stages of regional use. The stages so far proposed, however, rather local than regional, because provincial controls of sedimentation as well as of distribution of ancient organisms were particularly pronounced in Japanese Tertiary.

With no satisfactory stages of the regional use, one is forced to take an expedience: to determine the stratigraphic position of the strata in question in terms of the proposed provincial units, and relate the provincial unit to the ones of world-wide application by means of contained paleontological evidences whichever available.

Taking mainly the correlation of the Indo-Pacific Miocene Series with that of Europe in consideration, Glaessner (1953) introduced Lower, Middle, and Upper Miocene as divisions of the standard "time-stratigraphic" scale[8] by which regional Miocene stages established in various parts of the world are related. Following lines are worth citing here to explain his view.

> "Present method of correlation hardly justify world wide use of units below the rank of a Stage. The threefold division of the Miocene is being used by many authors in different regions as a time scale for inter-regional correlation which is free from the suggestion of precise contemporaneity with deposits of faunas at a distant type locality ingerent in the use of primarily local Stage names. It also obviates the arbitrary selection of one local set of names in preference to another for world-wide correlation. Yet it is free from ambiguity, as in the last 10 years or so a considerable measure of agreement has been reached about the manner in which the European Stages are to be distributed among the Middle Miocene=Vindobonian (Helvetian-Tortonian), Upper Miocene=Sarmatian are being used in the Vienna Basin by Papp and Thenius (1949) and Janoschek (1951) and the following authors agree in placing the Burdigalian in the Lower Miocene; Brönniman (1940) in Morocco, Henson (1950) in the Middle East, Colbert (1942) in India, Renz and Kupper (1947), Mohler (1949), van Bemmelen (1949, p. 108) in Indonesia, Finlay (1947) in New Zealand, Senn (1940), Cooke, Gardner, and Woodring (1943), H.H. Renz (1948) in America. The well known European textbooks by Fourmarier (1950) and Brinlmann (1948) follow the classification outlined above, with minor modifications." (Glaessner, 1953. p. 657).

The terms "lower" or "early" Miocene; "middle" or "medial" Miocene; and

8) Glaessner (p. 649) used the term time-stratigraphic with reference to the geologic-time units now being adopted by the American Commossion of Stratigraphic Nomenclature (1952).

"upper" or "late" Miocene are adopted in the present paper in the sense Glaessner introduced. They are not capitalized, because, as will be mentioned, we have only ample evidence to relate local Japanese provincial stages and zones to the units of world wide application.

Followings are the criteria once empolyed by Hanzawa (1950) as of useful in determining the geologic ages of the Neogene formations in northern Japan. Nemely:

1) *Lepidocyclina* (*Nephrolepidina*) *japonica* Yabe indicates Burdigalian Statge in European standard, when it is not accompanied with *Miogypsina kotoi* Hanzawa; and the Moniwa molluscan fauna is restricted to this horizon.
2) *Miogypsina-Operculina* assemblage occurs in formations stratigraphically above those yielding *Lepidocydlina* and/or the Moniwa molluscan fauna, and therefore is the equivalent of the Helvetian Stage in Europe.
3) The Tatsunokuchi formation in the Sendai area is of the Upper Pontian or Pliocene-Pontian by proboscidean fossils [e. g. *Bunolophodon sendaicus* (Matsumoto)], and is Lower Pliocene by molluscan faunules, and the Tatsunokuchi formation is the correlatives of the Wakimoto formation of Oga Peninsula from mollusks and smaller foraminifers contained.

To them it may be added that:

1) According to Asano (1951, p. 19), the stratigraphically highest occurrence of the genus *Cyclammina*, which has never been found in Pliocene strata in New Zealand, Java, Sumatra, Venezuera, and the Dominican Republic, has been in Japan the one "at a little above the base of the Kitaura formation", where the genus is represented by *Cyclammina japonica* Asano.
2) A diatom species *Rouxia californica* M. Peragallo which has so far been restricted to the Delmontian Stage in California was found, by the present study, from the Matazawa formation of the eastern margin of the Hirosaki Basin.

Recently, Kitamura (1958a) classified the Tertiary strata in Northeast Japan into seven stages mainly by their stratigraphic relations ascertained in the field. They are distributed in four sedimentary provinces including the Japan Sea Province for which the sequence in Oga Peninsula serves as the type. The stages are numbered in ascending order from I to VII, corresponding to the Nishioga group, the Daishima plus Nishikurosawa formation; the Onnagawa plus Minamihirasawa; the Funakawa; the Kitaura, the Wakimoto; and the Shibikawa, respectively, as are shown in Table I.

Accepting the view presented by Kitamura with regards to the stratigraphic equivalents of these formations in the other provinces, Kotaka recognized five molluscan zones which can be applied throughout Northeast Japan as the biostratigraphic units (1957, 1958). They are in ascending order, pO, O, F, K, and P, indicating that they are of pre-Onnagawa, Onnagawa, Funakawa, Kitaura, and "Wakimoto" and their correlative formations. They are also shown in Table 1.

By relating the above mentioned criteria to these provincial litho-, bio-, and resulted time-stratigraphic units, the following inference can be drawn, namely:

1) Kitamura's stage II, at least its upper part, is the middle Miocene, because it contains *Miogypsina-Operculina* assemblage.
2) Kitamura's stage VI is Pliocene, because it contains Kotaka's molluscan assemblage P, which is represented by that of Wakimoto and its correlative formations.
3) Kitamura's stage V is assumed to be of the upper Miocene, because it is the uppermost subdivision of the Miocene series in Northeast Japan. If the Matazawa formation is a correlative of the Maido and thus of the Kitaura as was assumed by Kitamura, and also by the present writer, as will be mentioned later, the finding of *Rouxia californica* strengthens this view, since the Delmontian Stage of California has been considered to be the equivalent of the Sarmatian Stage of Europe (Weaver et. al., 1944).

Thus, if Hanzawa's view that *Miogypsina-Operculina* bearing strata is a Japanese equivalent of the Helvetian is correct[9], Kitamura's stage III (correlatives of the Onnagawa formation), and Stage IV (correlatives of the Funakawa formation) come between the Helvetian and some part of the upper Miocene[10].

From the studies of diatom assemblages, the writer holds the view that the floral differences are more remarkable between the stage III and the stage IV, than between of stage IV, and stage V. Accordingly, he tentatively place the Onnagawa and its correlative formation (stage III) in middle Miocene, and the Funakawa and its correlatives (stage IV) to the upper Miocene together with the Kitaura and its correlatives (stage V).

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9) This involves the long debated problem of the geologic ages of *Desmostylus*, and *Vicarya* faunas to which the writer is not well prepared. Using findings of smaller foraminifera (Asano, 1953; Iwasa and Kikuchi, 1954; and Kitamura *et al.*, 1958) showing the related occurences with *Miogypsina-Operculina* orbitoid foraminiferal fauna as a clue, Yabe (1956) has arrived at the following conclusions: "The writer (Yabe] agrees with Hanzawa in considering the Nisikurosawa [=Nishikurosawa] formation with *Miogypsina kotoi*, but lacking *Lepidocyclina japonica*, to be geologically somewhat younger than the Moniwa formation of Sendai with the latter foraminifera. It is possible that the Nisikurosawa and Sugota formations may correspond to the lower part of the Ajiri formation of Siogama with *Vicarya yokoyamai* and the basal sandstone of the Niiyama formation with *Desmostylus* in its basal part to the upper part of the Ajiri with the same mammalian remains, though, strictly speaking, more palaeontological data are needed to support the correlation here expressed".

10) *Rouxia californica* is restricted to a narrow zone (Hanna, 1930a) at the middle of the Delmontian Stage.

Localities of the samples

(Charts 2, and 3)

1. Localities in Hirasawa village, Kitaura-machi, Oga City, Akita Prefecture (see Chart 2).

IGPS loc. no. Ak-45 : An exposure at the cliff behind a house standing at the north side of the road from Yunoshiri to Hatake via Hirasawa village. Two samples from the cliff. Ak-45-1, four pieces of dark grey diatomaceous approximately 5 m stratigraphically above the top of the Nishikurosawa formation; and Ak-45-2, two pieces of brown laminated diatomaceous mudstone, 2 m above the previous one. Collector : T. Kanaya. The Hirasawa diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak-46 : A sea cliff of eastern part of Hirasawa village. The upper half of the cliff is the Hirasawa diatomaceous mudstone member, the lower half, the Nishikurosawa formation. The sample was from brownish-grey diatomaceous mudstone 2.5 m above the top of the Nishikurosawa formation. Collector: T. Kanaya. Hirasawa diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak-48 : A road-side cutting west of Hirasawa village. The cutting is at the north side along the road from Yunoshiri to Hatake via Hirasawa village. The samples came from three horizons : Ak-48-3, three pieces of sandy diatomaceous mudstone, 2 m above Ak-48-1; and Ak-48-5, three samples of laminated brown diatomaceous mudstone, 2 m above-48-3. The lowest horizon is 2m above glauconitic flinty shale, basal strata of the Hirasawa distaomaceous mudstone member. Collector : T. Kanaya. Hirasawa diatomaceous mudstone member, Onnagawa formation. Miocene.

2. Localities in the area south of Hirasawa village, Kitaura-machi, Oga City Akita Prefecture (see Chart 2).

IGPS loc. no. Ak-47 : A road-side cutting at the north side of the road from Yumoto to Toga; approximately 1000 m south of Hirasawa village. Hirasawa diatomaceous mudstone member overlies the Nishikurosawa formation at the cliff. Three pieces of glauconitic sandy diatomaceous mudstone were collected within a thickness less than 1 m above the top of the Nishikurosawa formation. Collector : T. Kanaya. Hirasawa diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak-49 : At 1600 m south from Hirasawa village, and 600 m south from Ak-47. The samples were collected from two horizons : Ak-49-1, white diatomaceous sandy mudstone; and Ak-49-2, brown to dark grey diatomaceous clayey mudstone, the latter is at a horizon 1.5 m higher than the former, which is approximately 2.5 m above the top of the Nishikurosawa formation exposed near by. Collector : T. Kanaya. Hirasawa diatomaceous mudstone member, Onnagawa formation, Miocene.

3. Localities in a small NNE valley east of an unnamed hill (attitude 74 m), 2000 m SW from Kitaura-machi, Kitaura-machi, Oga City, Akita Prefecture (see Chart 3).

IGPS loc. no. A-53 : 670 m south from the 74 m hill. Four pieces of brown diatomaceous mudstone were collected at the exposure along the west side of the valley. The diatomaceous mudstone alternates with flinty shale, through a thickness of 2 m showing a transition from the porcellaneous shale below. The lower boundary of the Shinzan diatomaceous mudstone member is placed at the base of the alternation. Four pieces of brown diatomaceous mudstone were collected at a horizon just above this alternation, and is approximately 55 m higher than that of the base of the Onnagawa formation. Collector : T. Kanaya. Shinzan diatomaceous mudstone member of the Onnagawa formation, Miocene.

IGPS loc. no. Ak-45 : At 630 m south from the 74 m hill. Four pieces of black sandy diatomaceous mudstone were collected at the locality, which is stratigraphically 13 m. above the base of the member in this section. Collector : T. Kanaya. Hirasawa diatomaceous mudstone member, Onnagawa formation Miocene.

IGPS loc. no. Ak-55 : At 500 m south from the 74 m hill. Four pieces of brown impure diatomite, 35 m stratigraphically above the base of the member. Collector : T. Kanaya. Hirasawa diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak -56 : At 420 m south from the 74 m hill. Four samples of glauconitic sandy diatomaceous mudstone were collected at the exposure along the east side of the valley. The locality is 5 m stratigraphically below the top of the diatomaceous member. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

4. Localities on the Kamo-gawa side slope of Shimoshinzan village, Kitaura-machi, Oga City, Akita Prefecture (see Chart 3).

IGPS loc. no. Ak-57 : At the locality brown impure diatomite overlies flinty shale. Four pieces of impure diatomite were collected at the horizon 1.5 m above the top of the flinty shale. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak-58 : A road-side exposure of glauconitic sandy diatomaceous mudstone overlying impure brown diatomite. Four pieces of samples were collected from the sandy part which is stratigraphically approximatey 40 m above the base of the diato maceous member, and 20 m below the top of the member. Collector : T. Kanaya. Shinzan diatomaceous mudstone member Onnagawa formation, Miocene.

IGPS loc. no. Ak-59 : A cliff 7 m in heigh, with a 25 cm thick layer of poorly sorted very tuffaceous sandstone at the middle. Ak-59-1 is massive, pumice bearing sandy diatomaceous mudstone, 50 cm below the sandstone layer; and Ak-59-2 is 150 cm above the sandstone layer, where the strata is tuffaceous mudstone also diatomaceous. This is about the uppermost horizon of the diatomaceous rocks in this section. Mudstone is bluish colour at the upper part of this cliff where diatoms are lacking. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

5. Localities on the ridge or in the Ai-kawa side slope of Shimoshinzan village, Kitaura-machi, Oga City, Akita Prefecture (see Chart 3).

IGPS loc. no. Ak-61 : The south of Shimoshinzan village, 40 m east from the road from Shimoshinzan to Kamishinzan. The lowest part of the diatomaceous member. Several pieces of dark grey sandy mudstone were collected at the horizon, which is 5 m stratigraphically above the top of porcellaneous hard shale. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no.Ak-62 : ,The Diatomite quarry. White diatomite overlies dark grey sandy diatomaceous mudstone. Four pieces of white diatomite were collected at the horizon, which is 5 m stratigraphically above Ak-61, and 10 m above the base of the diatomaceous member in this section. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak-63 : The road side exposure of white diatomite and brown diatomaceous mudstone, in Shimoshinzan village, besides the road from Shimoshinzan to Kamishinzan. Three pieces of white diatomite were collected at the horizon, which is about 10 m stratigraphically above Ak-62, and 20 m above the base of the diatomaceous member in this section.

Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak-64 : A cutting 50 m east of Ai-kawa, beside the road from Shimoshinzan to Anzenji. Four species of glauconitic sandy diatomaceous mudstone, were collected at the locality which was estimated to be 25 m stratigraphically below the top of the diatomaceous member. Collector : T. Kanaya. Shinzan diatomaceous mudstone member of the Onnagawa formation, Miocene.

IGPS loc. no. Ak-65 : A cliff along the west-side of the Ai-kawa. The exposure has a 50 cm thick decomposed coarse pumiceous tuff layer. Glauconitic sandy mudstone underlyting the tuff layer is diatomaceous but bluish grey fine-grained tuffaceous sandstone above the tuff layer is not diatomaceous. The glauconitic sandy mudstone represents the top of the diatomaceous member. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

6. Localities in the narrow NE valley west of Anzenji and SE of an unnamed hill (attitude 136,5 m), Kitauramachi Oga City, Akita Prefecture (see Chart 3).

IGPS loc. no. Ak-66 : An exposure 220 m SW from the road from Shimoshinzan to Anzenji. The exposure is along the north wall of the valley. Four pieces of sandy distomaceous mudstone were collected at the locality, which is stratigraphically 10 m above the top of hard porcellaneous shale exposed near by. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation, Miocene.

IGPS loc. no. Ak-67 : An exposure along the north side of the valley, 170 m SW of Ak-66. Diatomaceous mudstone becomes sandy by glauconite grains. Four pieces of glauconitic sandy diatomaceous mudstone were collected at the locality, which is about 10 m stratigraphically below the top of the diatomaceous member in this section. Collector : T. Kanaya. Shinzan diatomaceous mudstone member, Onnagawa formation.

IGPS loc. no. Ak-68 : An exposure along the south side of the valley, 150 m SW from the road. Four pieces of glauconitic sandy diatomaceous mudstone were collected at the locality which represents the examined top of the diatomaceous member in this section. A sample from a strata 5 m (Ak-69) higher than this horizon was not diatomaceous.

Description of the Hirasawa and Shinzan diatomaceous mudstone members of the Onnagawa formation

Hirasawa diatomaceous mudstone member of the Onnagawa formation (Chart 2)

Type locality : Hirasawa village, on the north coast of Oga Peninsula, Kitaura-machi, Oga City, Akita Prefecture.

Stratigraphic position : Conformably overlies the Nishikurosawa formation. Upper boundary unknown.

Area of distribution : Around Hirasawa village, extending southward as far south as approximately 1600 m from Hirasawa village. (for map, see Huzioka, *et al.*, 1954).

Lithology : Mostly consists of diatomaceous mudstone sometimes glauconitic, and intercalates a few layers of thin black flinty shale. At its base, with 2 m thick layer of glauconitic flinty shale, or an alternation of flinty shale and mudstone both glauconitic.

Thickness : The obtained maximum 9 m.

Fossil contents : *Coscinodiscus Yabei* assemblage and the diatom assemblage A. No formanifera nor mollusks.

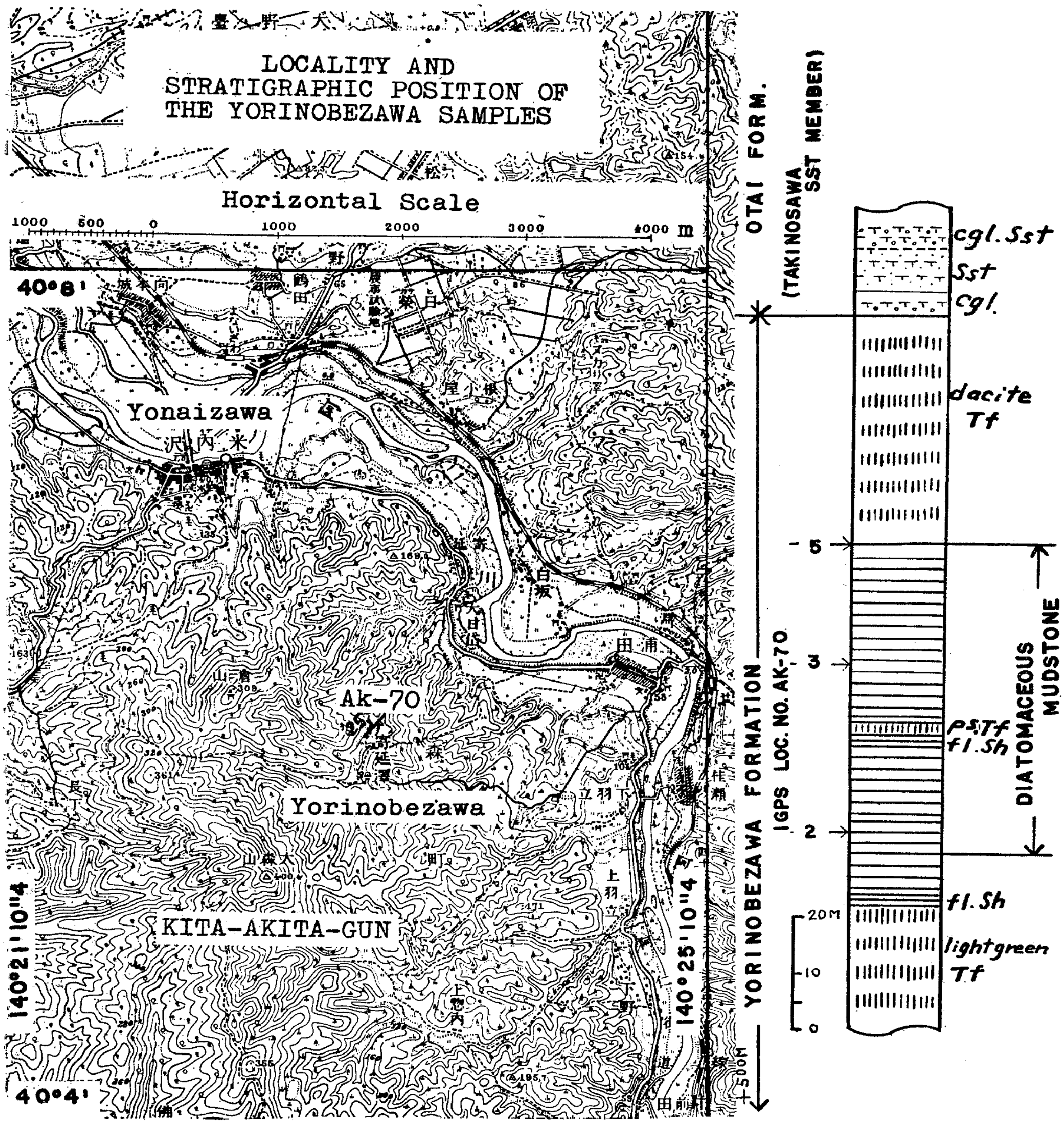
Geologic age : medial Miocene.

Comparison : The shale facies of Toyama (1952) of the Nishikurosawa formation.

Shinzan diatomaceous mudstone member, Onnagawa formation (Chart 3)

Type locality : Shimoshinzan, in the central part of Oga Peninsula, Kitaura-

Chart. 4



machi, Ogacity, Akita Prefecture.

Stratigraphic position: Developed in the upper part of the Onnagawa formation, and is overlain by the Minamihirasawa formation with a gradual transition. In the type section (Chart 3, section 9), the Onnagawa formation below this member has a thickness of 85 m, consisting of porcellaeous shale which frequently alternates with sandy mudstone, and conformably overlies the Nishikurosawa formation.

Lithology: Mostly consists of diatomaceous mudstone; diatomite to impure

diatomite in the middle; and sandy in the lower and upper parts, the latter being glauconitic.
Area of distribution: Typically exposed in Shimoshinzan, extending northwest, so far traced to 1.3 km from Shimoshinzan; and southeastwards 900 m where the member is thinning out.
Thickness: 50–60 m.
Fossil contents: Two diatom assemblages: *Coscinodiscus Yabei* assemblage and the assemblage C. No foraminifera nor mollusks.
Geologic age: medial Miocene.
Comparison: The Minamihirasawa formation of Huzioka (1950) includes the glauconitic upper part of this member. The newly named member corresponds to the Diatom earth (De) of the Onnagawa formation of Ohashi (1930).

Yorinobezawa Area, South of Yonaizawa, Akita Prefecture

(Chart 4)

Stratigraphy and correlation

T. Kotaka who placed the samples of diatomaceous mudstone he collected from the Yorinobezawa formation at the writer's disposal, classified, with R. Imaizumi, Tertiary rocks of the Takanosu, Odate and Yorinobezawa districts into the scheme (Imaizumi and Kotaka, 1952) as is shown in Table 1. The correlation with the strata of the neighbouring areas, and further with the sequence in Oga Peninsula was suggested mainly on the basis of lithologic similarities. Nevertheless, their view that the Yorinobezawa formation is the correlative of the Onnagawa formation of Oga Peninsula has been well accepted (Ishii et al., 1954; Kitamura, 1958b).

Concerning the Yorinobezawa formatin, Imaizumi and Kotaka stated that

> "The Yorinobezawa formation. The type locality is at Yorinobezawa, Yonaizawa-machi; 600 meters thick. This formation, has but narrow distribution in the central western part of the field [The Takanosu, Odate, and Yonaizawa districts]. It is characterized by white to light green tuffite at the lower, of diatomaceous-siltstone in the middle and with white to light green at the upper." (p. 29).

Chart 4 shows the locality and stratigraphic positions informed by Mr. Kotaka.

Localities of the samples

IGPS loc. no. Ak-70, Cutting immediately west of a pottery in Yorinobezawa, Yonaizawa-machi, Kitaakita-gun, Akita Prefecture. Three diatomaceous mudstones were collected by T. Kotaka. Ak-70-5: immediately below dacitic tuff layer; Ak-70-3, 20 m stratigraphically below Ak-70-5; and Ak-70-2, 30 m stratigraphically below Ak-70-3, and 10 m above flinty shale at the case of the diatomaceous rock in this section. Uppermost part of the Yorinobezawa formation, Miocene.

Marginal parts of the Hirosaki Basin, Aomori Prefecture

Stratigraphy

The geological work on the marginal parts of the Hirosaki Basin has been carried out during the summer of 1948, by S. Hanzawa, R. Imaizumi, S. Imanishi, and by the writer, Tohoku University, Sendai. The borderland of the basin was divided into three areas of responsibility, namely eastern margin, southern margin and western margin, covered by R. Imaizumi, T. Kanaya, and S. Imanishi, respectively. The stratigraphic relations then ascertained between Miocene and Pliocene strata exposed in the Basin (Imanishi, 1949; Imaizumi, 1949; and Kanaya, 1949) were summarized by Hanzawa (Hanzawa, 1949, MS., Hanzawa, 1954, p. 221) as is partly shown in Table 1. The tentative correlation then suggested between these formations in the basin and those exposed in Oga Peninsula was supported by later findings of adequate fossil evidences which make the correlation convincing.

The samples incorporated in the present study are those from the Owasawa formation of the southern margin of the basin, the correlative of the Onnagawa formation of Oga Peninsula, and the following formations which are grouped together as of the higher horizons in this paper. They are : the Iizume, and Matazawa formations of the eastern margin, and the Maido formation of the western margin of the basin.

The Owasawa formation (Kanaya, 1949) outcrops extensively in the eastern part of the southern margin of the Hirosaki Basin and its typical exposures are along the east side of the Owasawa, in the region of Oinomori to Owasawa villages. The formation is mostly composed of an alternation of siliceous shale or hard shale, and tuffaeous mudstone, totaling 600 m in maximum thickness in this area. The lowest part of the formation is a thick bedded light greenish or yellow-grey tuffaceous sandstone with thin siliceous shale layers, light green tuff, and tuffaceous sandstone. Green tuff-breccia sometimes occur in the lower part. An alternation of green siliceous or hard shale, and pumiceous tuff of the same colour is rarely found from the middle to upper parts of this formation. The Owasawa formation conformably overlies the Ainaigawa formation (Kanaya, 1949), the lowest unit of the Tertiary rocks in this field, has basaltic andesite flow and its green coloured coarse pyroclastics in the lower part which becomes finer grained toward the upper. The green rocks of the Owasawa formation make it difficult to draw a sharp line between the Ainaigawa, and therefore the base of the Owasawa formation was arbitrary place at the lowest layer of the siliceous shale.

A small amount of diatom frustules are contained within almost every part of the hard shale and tuffaceous mudstone of the formation, but their concentration plentiful enough to the present study are confined within the small restricted parts of the formation. The samples used in the present study were taken from tuffaceous mudstone with high concentration of diatoms, and it is quite important to ascertain whether these portions of high concentration are distributed within a definite horizon.

However, unfortunately, from the sequence which show the typical order of this formation, the writer never found mudstone with high concentration enough for usage of the woid "diatomaceous", and all samples used for the present study were excavated from the sequence that has been disturbed by dykes and fault, and therefore, critical relations among the different localities could not be determined either vertically or horizontally.

Of the five samples used for the present study, four (IGPS loc. nos. Ao-9–12) came from localities along Tochinaigawa, and one (IGPS coll. no. Ao–13) from at Matsukitai, which is about 9 km east from the Tochinai-gawa localities (see Chart 5). The first four, as will be mentioned later, came from the lower 250 m of the Owasawa formation in the area, though the relative positions were not precisely known. The strata exposed at the Matsukitai locality is judged to be of the uppermost portion of the Owasawa formation.[11]

The Iizume formation (Imaizumi, 1949) is typically exposed in the area along the Fudo-zawa, in the vicinity of Iizume-mura, in the eastern margin of the Hirosaki Basin. It is composed of a 100–550 m thick dark-grey to light grey mudstone, and conformably overlies the *Itadome formation* (Imaizumi, 1949) which consists of green tuff and silliceous shale totaling 100–260 m in thickness. The locality in the Fudo-zawa (IGPS loc. no. Ao-26) from where the diatomaceous sample was collected is stratigraphically 150 m below a 30 m thick sandstone which is the base of the overlying Matazawa formation.

The Matazawa formation of the eastern margin of the Hirosaki Basin (Imaizumi, 1949) is typically exposed along the Mata-zawa, the upper course of the Obuchi-gawa, Iizume-mura, Kitatsugaru-gun, attaining a thickness of 50–100 m. As just mentioned, the lower part of the formation is dark coloured, medium grained tuffaceous sandstone, and the upper part grey mudstone, which is highly diatomaceous at the exposure near Ishidasaka, Iizume-mura. Two samples (IGPS loc. nos. Ao–27, 28) of the Matazawa formation were collected from this diatomaceous part at two localities nearby and are approximately in the same horizon.

11) Mr. T. Iwai of the Hirosaki University is to propose the Matsukitai formation for the uppermost part of the Owasawa formation in his work on the area now in progress.

The Maido formation (Imanishi, 1949) is an alternation of siltstone, and tuffaceous mudstone in its type area on the Japan Sea coast: Maido-mura, Ajigasawa-machi, Nakatsugaru-gun, Aomori Prefecture. The formation, cropping out widely along the Nakamura-gawa, was traced southwardly along the western foot of Mt. Iwaki over a distance of 24 km to the southern foot of the mountain, where the formation is exposed in the gorge of the Taiaki-gawa. The Maido formation of the latter area is made up of sandy mudstone intercalating pumice, and tuffaceous sand layers, and often bears marl concretions. In this area, the strata are more pyroclastic than those in the type. Of the two samples incorporated in the present study, one (IGPS loc. no. Ao–24) came from the type area, and another from the locality in the Taiaki-gawa gorge, at 750 m NWW of Natsubotai, Nishimeya-mura, Nakatsugaru-gun, Aomori Prefecture.

The Tertiary sequence in the western margin of the Hirosaki Basin below the Maido formation was divided by Imanishi into three formations, namely in descending order, the Akaishi, Komori and Maenokawa formations.

The Akaishi formation (Imanishi, 1949) which underlies the Maido conformably, consists chiefly of dark grey, well bedded mudstone in the northern part of the western margin of the Basin, but of tuffaceous sandstone, sandy tuff, tuff, pumicestone, marl, and shale in the southern part of the western margin. The lateral change of facies is remarkable in this formation.

The Komori formation (Imanishi, 1949), is exposed typically in the vicinity of Komori, Akaishi-mura, Nishitsugaru-gun, and underlies the Akaishi with a gradual transition. It consists mostly of grey, hard shale and siliceous shale, attaining 150 m in thickness.

The Maenokawa formation (Imanishi, 1949) is developed typically in the area along a tributary of the Nakamura-gawa, Iwaki-mura, Nakatsugaru-gun, and comes below the Komori conformably, and has a thickness of 300 m. It is composed of dark grey, massive tuff-breccia at the base, grading upward to pale-green tuff breccia, to the part intercalating hard shale with marl concretions and silicified woods, and further to the upper part where the formation is soft green tuff breccia, with bluish-green, glauconitic, conglomeratic sandstone at its top. The formation sometimes bears coal seams and contains molluscan and plant remains which will be mentioned later.

Correlation

In the marginal part of the Hirosaki Basin, from the bluish green, glauconitic, granule conglomeratic sandstone of the uppermost part of the Maenokawa formation, Imanishi found the following molluscan fossils;

Patinopecten kimurai (Yokoyama)
Cardita siogamensis Nomura

Cardita sp.

In addition he also collected the following two plant fossils from a tuffaceous sandstone, about 50 m below the molluscan bed.

Liquidambar formosana Hance

Ulnus cfr. *longifolia* Unger

These fossiliferous beds of the Maenokawa formation are overlain conformably by the siliceous shale of the Komori formation. Though they are scanty, the plant fossils herein listed were thought to be comparable to the *Liquidambar "Componiphyllum"* flora of the Daijima formation of Oga Peninsula, and the molluscan fauna was also referred to the fauna that is usually associated with the horizon of the *Miogypsina-Operculina* assemblage (Kotaka's pre-O fauna, Kotaka, 1957). Accordingly, the Maenokawa and the Ainaigawa formations were considered as correlatives of the Daijima plus the Nishikurosawa formation of Oga Peninsula being upheld by stratigraphical relationships and the lithologic characters.

Recently, *Miogypsina kotoi* Hanzawa was found with *Operculina complanata* Defl. *japonica* Hanzawa from the upper part of the Kiyotakizawa formation (Hanzawa, *et al.*, 1958,; Kitamura *et. al.*, 1958) along the Japan Sea coast of the Tanosawa area, which is about 14 km west of Ajigasawa. This fossiliferous part of the Kiyotakizawa is the Tanosawa formation (Kitamura, 1957) of the Ajigasawa area, and the Tanosawa is the northwestern extension of the Maenokawa formation of Imanishi.

Furthermore, T. Iwai found molluscan remains from the upper part of the Ainaigawa formation in the southern margin of the Hirosaki Basin, which directly underlies the Owasawa formation from which the diatom samples were collected. By his preliminary study,[12] the molluscan fauna is what Kotaka calls pre-O fauna, the fauna which is usually associated with *Miogypsina-Operculina* foraminiferal assemblage, in Northeast Japan. Therefore, the correlation heretofore made is now supported by the sound faunal evidence.

Overlying thesep yroclastic rocks yielding *Miogypsina-Operculina* foraminiferal, pre-O molluscan fauna and *Liquidambar-"Comptoniphyllum"* floral assemblages (= the "Daijima type" flora) (thus stage II of Kitamura) are formations chiefly composed of hard or siliceous shales which are represented by the Odoji in Ajigasawa on the Japan Sea coast, by the Komori in the western margin, by the diatom-bearing Owasawa in the southern margin, and by the Itadome in the eastern margin of the Hirosaki Basin. The relation to the underlying rocks, and their lithology warrant the intra-basin correlation of these strata, and further, their correlation with the Onnagawa formation of Oga Peninsula, which serves as the

12) Study in progress. The writer is indebted to Mr. T. Iwai for permission to cite the unpublished data.

type of stage III in the Japan Sea Province.

The Akaishi in the western margin, and the Iizume in the eastern margin are both composed of dark-coloured mudstone of similar lithology, and hold the same stratigraphic position with regard to the underlying strata of Kitamura's Stage III. Furthermore, the Akaishi formation is conformably overlain by the Maido formation, which by its foraminiferal fauna, is proved to be the correlative of the Tentokuji and Katsurane formations (Kitamura, 1957, p. 15) of the Akita-oil field (see Table 1), and therefore, the strata of Kitamura's stage V, for which the Kitaura formation of Oga Peninsula also belongs. Hence, as Kitamura did (1958b), assigning the Akaishi and Iizume formations to that of Kitamura's stage IV, for which the Funakawa of the Oga Peninsula serves as the type is justified.

With the Maido formation just mentioned, the Matazawa formation of the eastern margin of the Hirosaki Basin is correlated, solely because two formations are in a same position in the stratigraphic subdivision established in the marginal part of the Hirosaki Basin.

The Maido has been considered to be Miocene in age, because it is the correlative of the Kitaura formation yielding *Cyclammina japonica*, and because the formation is conformably overlain by the Narusawa formation (see Table 1) which contains foraminiferal fauna of the Pliocene aspect comparable to that of the Wakimoto formation of Oga Peninsula.

The finding of a diatom species *Rouxia californica* M. Peragallo in the samples from the Matazawa formation serves as a clue in correlating the Miocene and Pliocend sequence of Japan with those of California coast, since the species, as will be mentioned later, has been known to be restricted to the Delmontian Stage in California, which is in the present paper, late Miocene in age.

From the stratigraphic records mentioned above, it is concluded that the Owasawa formation, which supplies five diatomaceous samples to the present study, is a correlative of the Onnagawa formation of Oga Peninsula.

The word "higher horizons" refers to two horizons stratigraphically higher than that of the Onnagawa and its correlatives. Namely, one is that of the Iizume formation, and the other is that of the Maido and Matazawa formations. The former belongs to stage IV of Kitamura (correlatives of the Funakawa formation of Oga Peninsula) and the latter is one stage higher, being of stage V of Kitamura (the correlatives of the Kitaura formation of Oga Peninsula), and both are late Miocene in age. Five samples of these formations were examined for the comparative purpose.

Localities of the samples

Owasawa formation (Chart 5)

IGPS loc. no. Ao-11 : East cliff of the Tochinai-gawa, about 900 m N 60° E from Omori Hill, Shimizu-mura, Hirosaki-shi, Aomori Prefecture. Lat. 40°33′22″ N., Long. 140° 24′25″ 4 E. Four samples of dark grey diatomaceous mudstone were collected in September, 1948, from about 150 m. above the base of the Owasawa formation. Collector : T. Kanaya. Miocene.

IGPS loc. no. Ao-10 : East cliff of the western tributary of the Tochinai-gawa, about 1250 m S 30°E from Omori Hill, 1200 m south of loc. no. Ao-11, Shimizu-mura, Hirosaki-shi Aomori Prefecture. Lat. 40°32′40″N., Long. 140°24′23″ 4 E. Three samples of dark grey diatomaceous mudstone were collected from approximately the same horizon as Ao-11. Collector : T. Kanaya. Miocene

IGPS loc. no. Ao-12 : West cliff of the Tochinai-gawa, 1625 m N 42° E from Omori Hill, 50 m downstream from the bridge, and about 1000 m north of loc. no. Ao-11, Shimizu-mura, Hirosaki-shi, Aomori Prefecture. Lat. 40°33′48″ N, Long. 140°24′40″4 E. Four samples were collected from a horizon about 100 m higher than that of loc. no. Ao-11. Collector : T. Kanaya. Miocene

IGPS loc. no. Ao-9 : East cliff of the Tochinai-gawa, about 150 m north from loc. no. Ao-11, Shimizu-mura, Hirosaki-shi, Aomori Prefecture. Lat. 40°33′24″ N., Long. 140° 24′25″4 E. Four samples of black distomaceous mudstone were collected.

IGPS loc. no. Ao-13 : North cliff along a road cut in a small unnamed hill of 83 m height, about 1100 m NW from the shrine at Osawa village, Matsukitai, Chitose-mura, Hirosaki-shi, Aomori Prefecture. Lat. 40°33′11″ N., Long. 140°30′34″ E. Four samples of brownish yellow tuffaceous diatomaceous mudstone were collected. The locality marks exposed top horizon of the Owasawa formation in the area south of Hirosaki city.

Iizume formation

IGPS loc. no. Ao-26 : North cliff along the road immediately south of an unnamed hill of 72 m in attitude, in Fudo-zawa, Iizume-mura, Goshogawara-shi, Aomori Prefecture. Four pieces of grey diatomaceous mudstone were collected approximately 150 m stratigraphically below the base of the overlying Matazawa formation. Collector : T. Kanaya. Miocene.

Matazawa formation

IGPS loc. no. Ao-27 : South cliff at the south of a dam in Ishida-saka, Iizume-mura, Goshogawara-shi, Aomori Prefecture. Four pieces of light grey diatomaceous mudstone were collected. Upper part of the Matazawa formation. Collector : T. Kanaya. Miocene.

IGPS loc. no. Ao-28 : cliff at the immediately west of the dam in Shidasaka, Iizume-mura, Goshogawara-shi, Aomori Prefecture. Four pieces of light grey diatomaceous mudstone were collected. Upper part of Matazawa formation, within a thickness of 10 m above Ao-27. Collector : T. Kanaya. Miocene.

Maido formation

IGPS loc. no. Ao-24 : South cliff immediately SW of the Narusawa-gawa bridge, approximately 2000 m NE from Ajigasawa station, Maido-mura, Nishitsugaru-gun, Aomori Prefecture. Assumed to be the upper part of the Maido formation. Four pieces of diatomaceous mudstone were collected. Collector : T. Kanaya. Miocene.

IGPS loc. no. Ao-25 : South cliff in the Taiaki River gorge, showing the basal part of the Higashimeya formation at the middle of the cliff. At 800 m NW from the bridge at Nakubotai, Nishimeya-mura, Hirosaki-shi, Aomori Prefecture. Four pieces of sandy diatomaceous mudstone were collected from the cliff at a horizon immediately below the base of the Higashimeya formation. Collector : T. Kanaya. Miocene.

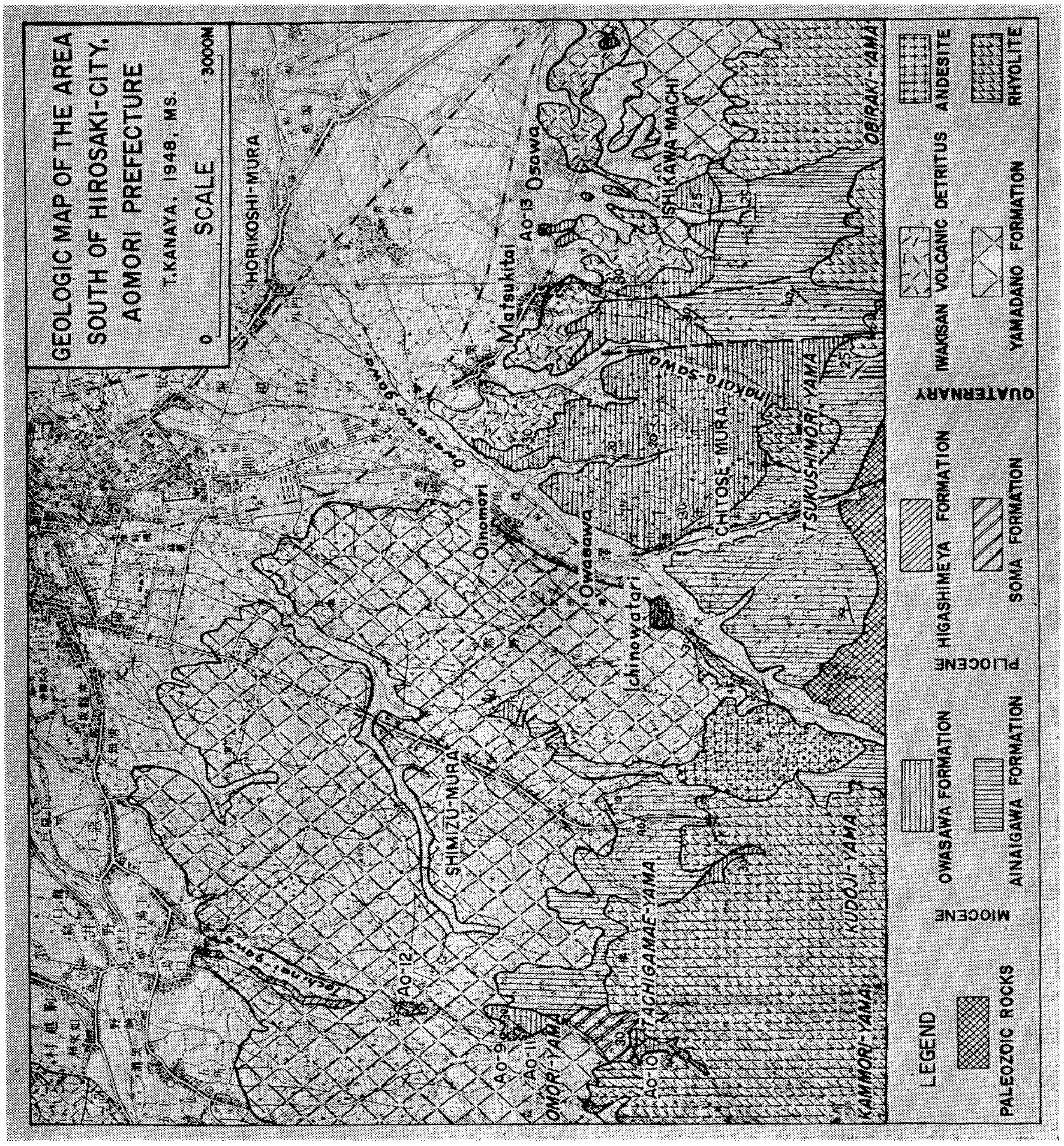

GEOLOGIC MAP OF THE AREA
SOUTH OF HIROSAKI-CITY,
AOMORI PREFECTURE
T. KANAYA, 1948, MS.
SCALE
0
3000M
HORIKOSHI-MURA
Matsukitai
Ao-13
Osawa
ISHIKAWA-MACHI
Oinomori
Owasawa
Ichinowatari
CHITOSE-MURA
TSUKUSHIMORI-YAMA
OBIRAKI-YAMA
SHIMIZU-MURA
Ao-12
Ao-9
Ao-11
Ao-10
OMORI-YAMA
TACHIGAMAE-YAMA
KUDOJI-YAMA
KAMMORI-YAMA
LEGEND
PALEOZOIC ROCKS
MIOCENE
OWASAWA FORMATION
AINAIGAWA FORMATION
PLIOCENE
HIGASHIMEYA FORMATION
SOMA FORMATION
QUATERNARY
IWAKISAN VOLCANIC DETRITUS
YAMADANO FORMATION
ANDESITE
RHYOLITE

CHART 5

CHAPTER II

PREPARATION OF MATERIALS AND METHOD OF STUDY

A composite sample obtained by mixing four to six pieces of diatomaceous rocks of equal weight represents a locality. The rock pieces were collected at the locality along the bedding plane within a thickness of 50 cm. When apparent changes in lithology were observed at an exposure, the samplings were made from each of the units of the different lithologies.

Cleaning Procedure

For samples thus obtained the cleaning procedure once described by the present writer (Kanaya, 1957, p. 41) was followed. A caution rules, of course, to treat samples equally, especially in the decantation intervals, so that the statistics from the cleaned residue are comparable.

The procedure was imporved by modifying in the following points. Namely, instead of 400 cc beaker, 200 cc ones are used at the present study. This makes the water column in the beaker 7 cm, compared to 10 cm as was applied previously. The intervals of decantations, however, are the same.

Before applying the process (1), 5 grams of the granulated sample are placed in a 200 cc beaker with distilled water. About 3 grams of tetra sodium pyrophosphate are added, and the sample is set aside to stand for 24 hours (Fizzel and Middour, 1951. p. 4). This disperses clay in the sample. The sample is stirred in the beaker; allowed to stand for 2 hrs. Finer suspensions are removed by careful decantation, and the coarser residue left at the bottom is then subjected to the acid treatment of the process (1).

For the process (4), a glass tube secured vertically to a wood stand is used, instead of a beaker. The tube has one end tapered; the diameter of the upper end is 3 cm of the lower end is 1 cm; and the tapering lower end is curved in U-shape which is open to be connected with a rubber tube. To hold water in the glass tube, the rubber tube is pressed to shut by a pin. The residue obtained by the process (3) is stirred while adding 50 cc of distilled water, and then is poured into the glass tube containing water as high as 30 cm from the bottom. The suspension is allowed to stand for 20 seconds; heavier residue reaching the bottom is separated by opening the rubber tube at the bottom; the lighter fraction still left suspending in the water is collected into a beaker to settle. The settled final residue, in which the diatoms are concentrated, is used for the study as a cleaned sample representing a locality.

Preparation of Slides

The method for preparing slides for microscopical examination was also described by the writer in his previous paper (1957, p. 42).

The same procedure was applied, though slightly different in detail for preparing strewn slides.

(1) 0.1 cc of the cleaned sample was placed in a graded mess cylinder with 10 cc of distilled water, and shaken to make a suspension. This is taken as *one unit suspension*. The writer found that 1/8 unit suspension gives the suitable thickness for counting of most of the present samples. For samples whose diatom density is much lower than the average, it is desirable to make the slide with 1/4 unit suspension to save time for counting. The solution of the desirable unit can be obtained by dilution. To keep the amount of suspension to be placed on the slides by the next process constant, the height of the column of the suspension should be constant. For this reason, the dilution was done in the same mess cylinder. After shaking, half of one unit suspension was removed by using a glass tube to obtain the suspension equally from each layer; distilled water was then added to the mess cylinder to 10 cc which makes the suspension 1/2 unit. To obtain the 1/8 unit suspension, the process was repeated three times.

(2) A glass tubes, appr 2.5 mm in inner diameter was used to transfer the suspensions in the mess cylinder to a cover glass. The 10 cc of the suspension attained 7.5 cm in height in the mess cylinder used; the amount taken was appr. 0.4 cc; and the diameter of the circular cover glasses used is 15 mm in diameter.

(3) The cover glass is dried gently to prevent from bubbling. When dried, it is mounted on a slide with Hyrax or Pleurax. The slids are then dried on an iron plate, keeping the temperature around 80°C, until the cover glass is firmly fixed on the slide during cooling.

Maltwood's Finder

(Figure 1)

The writer used Maltwood's finder to register the necessary specimens for taxonomical studies. One of the problems always faced is how to record the position of a specimen in a strewn slide in a simple and sure method, so that the specimen can be located easily whenever it is necessary. The Matlwood's finder solves this problem, when the specimens are fixed solidly by mounting the medium to the cover glass, as in the present case.

A brief outline about the finder may be useful to those who are working on diatoms as well as on silicoflagellata, radiolaria, pollen and spores.

The finder was made by the followinq method. First, a quadrate divided into 50 and 25 grids along the horizontal, and vertical axes, respectively, was drawn on a paper of a convenient size. Each square was numbered, by combining alphabet and numeral letters starting from the upper left. Thus, squares along the first horizontal line carry numbers A1, A2, ... A 50, from left to right, and squares in the left most vertical line is numbered as A1, B1, C1, ... YI, starting from the top.

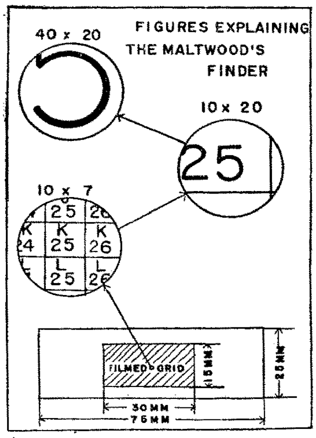


Fig. 1.

The numbered grids drawn was then reduced on 35 mm minicopy film by taking its picture using an ordinary camera. The writer reduced the gridded rectangular to 30 mm×15 mm.

The developped negative of the rectangular was cut out from the film and fixed on an oridinary slide by Canada balsam using the same technique as of making thin section slides of rocks. The finder thus prepared has a rectangular divided into 1250 numbered squares which are to be read under the microscope.

With the finder, a specimen in the strewn slides can be registered by taking the following steps.

(1) Place the specimen to be registered under the center of the microscope field by using a mechanical stage. Higher magnification (40×15 to 40×20) is desirable to make it accurate.

(2) Take the strewn slide off, leaving the mechanical stage in the same position. Then insert the Maltwood's finder to where the strewn slide was keeping the mechanical stage unmoved. Two sides of the finder, left and lower sides, should be adjusted to fit the mechanical stage.

(3) The microscope is focused to the finder (use lower magnification; 10×20) and the number the square carrying and the position of field center in the square are recorded (see Fig. 1; K–25 SE in this case).

The specimen thus registered can be easily brought under the microscope

1) Dr. R. Holmes of the Scripps Institution of Oceanography first provided me with a finder made by printing the grid on a film plate, while the writer was at the institution. The method of making the finder here described was developed by Kanaya, and Mr.K. Soma who specializes palynology at the Institute of Biology, Tohoku University. Later, Mr.K. Tsumura of the Yokohama City College kindly called our attention on the fact that the finder we have been using is what Van Heurck (1893) introduced more than a half century ago as the Maltwood's finder. Van Heurck's original paper has not been accessible to the writer.

whenever needed, by placing the strewn slide containing the specimen at the position as it was when the specimen was registered.

(1) Read the registered position of the specimen, and by using the mechanical stage locate that reading on the Maltwoods' finder at the center of the field of the microscope. In the case shown on Fig. 1, it was K–25 SE.

(2) Remove the finder, and insert the strewn slide carrying that specimen, keeping the mechanical stage unmoved. The registered specimen can be found under the field.

To keep this procedure successuful caution should be given to ;

(1) The strewn slides should be thoroughly dried to prevent the mounted specimens from moving while storing.

(2) The filmed grid should be fixed solidly on the deck glass to avoid its chance to move.

The procedure making use of the Maltwood's finder have definite advantages over other methods previously suggested. By this method, one can use a microscope whichever is available to him wherever he is, provided that the microscope has a good mechanical stage.

The only disadvantage is that the finder to which many specimens are registered, can not be replaced by another. It is almost impossible technically, to make duplicates of a finder for interchangeable use. When a finder is broken or chipped, which rarely happens, the specimens registered by the finder are lost into thousands of other specimens contained in the same strewn slide.

Method of Study

Stratigraphic positions of the samples, and frequencies and relative abundances of the species in the samples serve as the basis on which the present analysis of the Miocene diatom thanatocoenose is made. The frequencies and relative abundances of the species in the present samples are obtained by counting 200 diatom valves from each sample. At least two strewn slides were prepared to represent a sample.

The magnification used for the counting was 40×20, which gave a field under the microscope 0.17 mm in diameter. The cover glass on which the diatoms were strewn is 15 mm in diameter. Thus when the observation is made by traversing the middle line of the cover glass, the area covered are $0.17\ \text{mm}\times15\ \text{mm}=2.5\ \text{mm}^2$. This served an *unit area*. Seven parallel lines, including the middle one, were chosen randomly to traverse a cover glass. The chosen lines were numbered in order of the random numbers they carry. The total area that should be covered by traversing the cover glass along the chosen lines amount to 5.5 unit area, that is $2.5\ \text{mm}^2\times5.5=13.7\ \text{mm}^2$. The positions of the lines chosen on a cover glass of 15 mm diameter can be located on all strewn slides by reading their distances from the middle line on the Maltwood's finder.

By using a mechanical stage the counting was proceeded along the chosen lines, in order of their numbers. All specimens which appeared while traversing the slide along the chosen lines were identified and counted. The counting was continued until the 200th specimen was noted, and the area covered to find 200 specimens was recorded in terms of the unit area. When the specimens counted from the seven lines of a slide, that is from 5.5 unit areas, were less than 200, the counting by the same procedure was continued on another strewn slides of the sample to get the total number of 200. For the samples in which the diatoms are relatively rare, more than four strewn slides had to be prepared to get 200 specimens counted.

The frequencies of each species thus obtained by the single count of 200 specimens from each of all samples were recorded in the distribution chart (Chart 6) on which the values are arranged in stratigraphic order to show fluctuation through the sequence.

To check the occurrences of very rare species which do not appear in the counting of 200 specimens, two strewn slides for each sample were examined by the whole areas under the same magnification as was applied for the counting. The species found by such examinations are indicated by a solid circle in the distribution chart, and are distinguished from absence, which means in the present study the absence in the two strewn slides examined for a sample.

The number of areas required to find 200 specimens is in a reciprocal proportion of the diatom density in the caleaned residue. If 5.5 unit areas were required to be examined on the strewn slides of one sample to obtain 200 specimens, while the strewn slides of another sample contain 200 specimens in 11 unit areas, the former should have diatom valves twice as much as the latter in the same volume of the cleaned residue, inasmuch as the procedure applied to have prepared the strewn slides were such that makes this comparison possible. The reciprocals of numbers of the unit area required to obtain 200 diatom valves on the strewn slide of a standard thickness are here called *relative diatom densities*. The standard thickness applied for the present study is 0.4 cc of 1/8 unit suspention on a circular cover glass, 15 mm in diameter. Thus, if 3 unit area was required, the relative diatom density of the sample (represented by its cleaned residue) is 1/3.

Depository of Slides

The strewn slides containing the registered specimens will be deposited in the collection of the Insitute of Geology and Paleontology, Tohoku University, Sendai (abbreviation: IGPS), Japan.

CHAPTER III

DESCRIPTION OF ASSEMBLAGES

Distribution Chart

Available data to be incorporated in the present analysis of the diatom assemblages are gathered in the distribution chart (Chart 6).

The observed frequencies of species obtained by a random sample of 200 diatom valves for each sample are shown in the chart. The chart includes the distribution of diatoms in 25 samples from the Onnagawa formation, three from the Yorinobezawa formation, five from the Owasawa formation, and five samples of the higher horizons (of late Miocene in the present paper) : one from the Iizume, two from the Maido, and two from the Matazawa formations. The stratigraphic notes about the formations are given in Chapter I.

In the chart, the sample localities are arranged from left to right in ascending the order of positions in a section or in a composite section in each area, which are shown by corresponding numbers to those numbering the columnar sections given in Charts 2, 3, and 4. For details of the stratigraphic relations of the samples, the readers are referred to Chapter I.

The species and varieties are arranged in alphabetical order. The forms counted together are entered under one item. Thus *Grammatophora* spp. includes three undetermined forms of the genus; *Rhizosolenia* spp. four forms; and *Xanthiopyxis* spp. six undetermined forms besides *Xanthiopyxis oblonga*.

Miscellanea is referred to those forms whose studies are reserved for the future, either because (1) specimens good enough to warrant taxonomic discussions were not found in the present samples; or (2) while they were very rare in the Onnagawa and its correlative formations, examination of five samples from the higher horizons suggests their having more important roles in the younger assemblages, the details of which is beyond the scope of the present study. The first group includes :

small *Biddulphia*
Conscinodiscus ? *bicurvatulus* Lohman
Conscinodiscus ? *Kützingii* Schmidt
Conscinodiscus ? *nodulifer* Schmidt
Conscinodiscus stellaris var. *symbolophora* (Grun.) Jörd.
Cyclotella ? sp.
Entogramma cfr. *laevis* Grun.
Hantzschia sp.
Hemidiscus sp.

DISTRIBUTION CHART

CHART 6

AREA / FORMATIONS / SECTION NO. — PREVIOUS RECORD OF OCCURR. (Up. Creta., Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, Recent)

HIRASAWA AREA — HIRASAWA DIAT. MDST. MEMBER

Species	ECOLOGY	Previous record	(5) AK-49-1	(5) AK-49-2	(6) AK-47	(1) AK-48-1	(1) AK-48-3	(1) AK-48-5	(3) AK-46	(4) AK-45-1	(4) AK-45-2
1. Actinocyclus Ehrenbergii	N?										
2. Actinocyclus Ehrenbergii var. tenella						4					1
3. Actinocyclus ellipticus var. javanica			2							•	
4. Actinocyclus ingens					1	25	12	9	15	12	3
5. Actinocyclus tsugaruensis, n. sp.			4	2	15	12	12	9	15	5	3
6. Actinoptychus senarius			11	11	1	5	5	14	6	34	12
7. Actinoptychus splendens var. Halionyx											
8. Arachnoidiscus Ehrenbergii	S										
9. Asteromphalus moronensis								2	1	•	1
10. Aulacodiscus amoenus var. hungaricus	S?										
11. Cladogramma californicum									1	1	
12. Cocconeis antiqua	S?	?									
13. Cocconeis curvirotunda	S	?									
14. Cocconeis formosa	S?									1	
15. Cocconeis vitrea	S										
16. Coscinodiscus argus	O		4	12	1	1		2	1	1	1
17. Coscinodiscus curvatulus var. odontodiscus	N		1	1							•
18. Coscinodiscus elegans			2		1	2	1		3		
19. Coscinodiscus Endoi, n. sp.			1	1			8	24	7	5	5
20. Coscinodiscus excentricus											
21. Coscinodiscus hirosakiensis, n. sp.			1			1			5		
22. Coscinodiscus lineatus	O				1				•	1	1
23. Coscinodiscus marginatus	O		19	18	22	33	11		4	3	1
24. Coscinodiscus oculus-iridis	O		1		1			2	1	4	
25. Coscinodiscus radiatus	O				3	3	1	5		6	1
26. Coscinodiscus Rothii	N										
27. Coscinodiscus Temperi		?				•					1
28. Coscinodiscus vetustissimus		?	4	1	1	1	•	1	•	•	1
29. Coscinodiscus Yabei, n. sp.							2	7	10	2	3
30. Denticula lauta	O		23	25	10	52	33	22	48	58	123
31. Denticula ? sp.					64	28	23				
32. Dicladia capreolus			1			1				2	1
33. Endictya japonica, n. sp.											
34. Fragilaria hirosakiensis, n. sp.			94	90	26	7	35	53	26	13	15
35. Grammatophora spp.	S?		1		1	1	1				
36. Melosira granulata	F									1	
37. Melosira sol	S?								1		
38. Melosira sulcata	S		5	14	2	1		3	3	1	
39. Rhizosolenia spp.			1		2	3	9	17	14	15	1
40. Rouxia Peragalli		?		1				3			1
41. Rutilaria epsilon											
42. Stephanogonia Hanzawae, n. sp.				1	4	1	•	3	4	2	3
43. Stephanopyxis cfr. ferox				2	1	•	4	3	3	4	4
44. Stephanopyxis cfr. nipponica	N		1				1				
45. Stephanopyxis Schenckii, n. sp.			1	2		•	1	2	1		1
46. Stephanopyxis turris	N?				1	1	1	•			2
47. Stephanopyxis ? limbata var. Crista-galli		?						•		•	
48. Thalassiosira decipiens	N			5							
49. Thalassiothrix longissima	O		11	6	7	2	10	3	3	2	1
50. Triceratium sp. α								3			
51. Triceratium sp. β											
52. Xanthiopyxis acrolopha											
53. Xanthiopyxis spp.			4	4	21	11	9	8	9	15	6
Total number in N=200			192	196	186	195	179	195	181	188	192
Miscellanea			8	4	14	5	21	5	19	12	8
Number of sublittoral+neritic species: number of species appeared			4/21	4/17	4/21	5/24	4/21	3/23	3/24	2/26	4/25
Number of oceanic species: number of species appared			5/21	4/17	7/21	5/24	4/21	5/23	6/24	7/26	6/25
Number of sublittoral+neritic individuals (valves) in 200			19	31	5	12	7	17	10	35	15
Number of oceanic individuals (valves) in 200			58	61	45	91	55	34	57	75	128

SHINZAN AREA — SHINZAN DIATOMACEOUS MUDSTONE MEMBER

Species	(7) AK-53	(7) AK-54	(7) AK-55	(7) AK-56	(8) AK-57	(8) AK-58	(8) AK-59-1	(8) AK-59-2	(9) AK-61	(9) AK-62	(9) AK-63	(9) AK-64	(9) AK-65	(10) AK-66	(10) AK-67	(10) AK-68	(10) AK-69
1.			6														
2.	1							3									
3.	•		2	2					•	•							
4.	11	20	1	1	3			•	2	7	12		•	•	1		
5.	12	5	1	2	1			1	7	3	3						
6.	13	10	1	7	5	11	3	20	6	2	3		10	15	6		
7.																	
8.												2		1		•	
9.	1	1											•				
10.																	
11.								1									
12.							1	1			•	1	1	1			
13.												•	2	•	•		
14.	1					1	1	2				4	1	3			
15.											•						
16.	6	8	4	3				•	1	1	1						
17.			2		1		1	1	1	1	2		2		2		
18.		2			•				•	2	•	2	2				
19.	12			1	5				1		6	2			2		
20.	1	12	1				3					2	2		1		
21.	1	2	2		2		1		3		•	3	2				
22.		1	1	1				2					1	1			
23.	11	1		•	1	168	10	45	2	1	1	86	80	54	131	192	
24.	2	2	3						1			2			2		
25.	5	1		2		1	1		3	1		4					
26.			2								1		1		2		
27.												•			2		
28.	•		11	1	5			5	12		2						
29.	•	•	12		7					6	3						
30.	10	58	28	46	17		56	23	29	41	27	5	14	3			
31.					•						2						
32.	1			•		2					•						
33.	2		1	•		1			•			3		1	2		
34.	21	22	22	78	132	2	42	34	101	92	108	33	54	75	15		
35.	•						1				3	2	1			2	
36.	2						3	1					1				
37.	2					1	2	3			•		•				
38.			1	1			4	3		2	1		1	3	3	4	
39.	15	13	5	5	1		3	10	2	6	2		6	2	13		
40.	1		9				1		1	4	1			1			
41.								•									
42.	3	•			12				2	4	2						
43.	6	3	•	1	•	1			1			3	•		•		
44.								3						1			
45.	2	1		•					•	2							
46.			1		2			2	1								
47.																	
48.	1		•				•	6		•		7	2		5		
49.	12	14	50	39	4	1	31	20	13	16	11	8	9	10	4		
50.									1	1							
51.			•								•						
52.			•		•												
53.	13	2	10	1	1	1	11	4	5	6	1	6	5		1		
Total number in N=200	168	178	176	191	199	190	175	190	195	198	192	175	197	171	192	198	
Miscellanea	32	22	24	9	1	10	25	10	5	2	8	25	3	29	8	2	
Number of sublittoral+neritic species: number of species appeared	7/32	1/21	9/27	2/20	3/20	3/11	8/19	10/24	3/25	4/21	10/27	4/20	10/24	7/16	6/18	3/4	
Number of oceanic species: number of species appared	6/32	7/21	5/27	6/20	3/20	3/11	4/19	5/24	6/25	5/21	4/27	6/20	4/24	4/16	3/18	1/4	
Number of sublittoral+neritic individuals (valves) in 200	23	10	13	8	8	13	13	44	8	5	6	14	19	21	10	6	
Number of oceanic individuals (valves) in 200	46	85	86	91	22	169	98	90	49	59	40	101	104	68	135	192	

YORINOBE-ZAWA — HIROSAKI BASIN

Species	YORINOBE-ZAWA F. (11) AK-70-2	AK-70-3	AK-70-5	OWASAWA F. AO-10	AO-11	AO-9	AO-12	AO-13	MAIDO F. AO-24	AO-25	IIZUME F. AO-26	MATA-ZAWA F. AO-27	AO-28
1.	•	•	•							1			
2.	1		1	2	2			2			1		
3.													1
4.	20	15	12	20	15	12	10	9	•		•	1	•
5.	2	2	7		25	2	•	2				2	
6.	6	60	6	3	3	19	4	8	1	6	5	12	20
7.								•					
8.		1			1	•		•	2	•	•	1	
9.			13	1									1
10.								•				1	
11.								•					
12.			1					•	•	•			
13.				•					•	•	1		1
14.													
15.													
16.	2	1			1		1	3	1	6			1
17.		1	2		2								
18.	3	3	•	2	5	3	4	51	3	2			1
19.	24	10	17	5	5	16	12						
20.				1					3	2			
21.	1				2		•	1	1	2			
22.									3	1	2		
23.				1	3	4	1	13	65	22	35	46	32
24.	1								4	1			
25.			1	1	2			2	4	2		1	
26.										1			
27.								•	2				
28.	6	1		9	19	3		3		1		1	1
29.	6	4	10	1	1	3	5						
30.	19	38	45	43	28	54	42	11	1			1	2
31.	3					29	17			3		1	
32.						•			1	1			
33.								1	2				1
34.	33	17	25	64	28	30	46	9	8	24	130	46	50
35.							•	5	8	1	1	4	3
36.					2		2			2	2	2	
37.			1					4	4	1		2	3
38.	6	3	1		6		2	11	5	20	1	9	3
39.		10	6	28	20	10	16	7				5	1
40.	11					3	6					13	39
41.			•					•					
42.	2	•	3		•	•	•		•				
43.	1	5	2	1	1	•	1	1					
44.	•												
45.	1	•			•		1	•					
46.	5	1			2		1	•	35	24		1	
47.													
48.							1		4	26	1		2
49.	2	1	5	3	2	5			1	1	4	10	15
50.		1											
51.													
52.													
53.	18	9	16	4	16	4	3	8			3	1	1
Total number in N=200	172	183	175	189	191	197	175	157	158	150	186	160	178
Miscellanea	28	17	25	11	9	3	25	49	42	50	14	40	22
Number of sublittoral+neritic species: number of species appeared	6/24	6/22	7/22	2/17	7/26	3/19	6/23	13/28	9/25	11/25	7/14	7/20	6/19
Number of oceanic species: number of species appared	4/24	3/22	2/22	3/17	4/26	3/19	3/23	3/28	6/25	5/25	3/14	3/20	4/19
Number of sublittoral+neritic individuals (valves) in 200	27	66	12	5	16	19	6	30	59	80	9	30	32
Number of oceanic individuals (valves) in 200	24	40	50	47	34	63	44	27	75	31	41	57	50

Relative Diatom Densities (0, 0.2, 0.4, 0.6, 0.8, 1.0)

ALMOST BARREN OF DIATOMS

EXPLANATION OF ECOLOGICAL REMARKS (FROM JOUSÉ, 1957)

S : SUBLITTORAL

N : NERITIC

O : OCEANIC

F : FRESHWATER

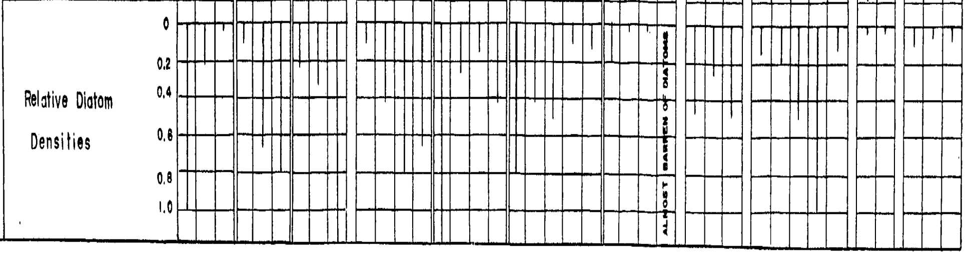
AN INTEROGATION MARK INDICATES THAT THE ASSIGMENT IS INFERRED FROM ALLIED FORMS

DISTRIBUTION CHART

CHART 6

Species	ECOLOGY	Up.Creta.	Paleocene	Eocene	Oligocene	Miocene	Pliocene	Pleistocene	Recent	AK-49-1	AK-49-2	AK-47	AK-48-1	AK-48-3	AK-48-5	AK-46	AK-45-1	AK-45-2	AK-53	AK-54	AK-55	AK-56	AK-57	AK-58	AK-59-1	AK-59-2	AK-61	AK-62	AK-63	AK-64	AK-65	AK-66	AK-67	AK-68	AK-69	AK-70-2	AK-70-3	AK-70-5	AO-10	AO-11	AO-9	AO-12	AO-13	AO-24	AO-25	AO-26	AO-27	AO-28
AREA										HIRASAWA AREA									SHINZAN AREA																	YORINOBE-ZAWA			HIROSAKI BASIN									
FORMATIONS										HIRASAWA DIAT. MDST. MEMBER									SHINZAN DIATOMACEOUS MUDSTONE MEMBER																	YORINOBE-ZAWA F.			OWASAWA F.					MAIDO F.		IIZUME F.	MATA-ZAWA F.	
SECTION NO.										(5)		(6)	(1)			(3)	(4)		(7)				(8)				(9)					(10)				(11)												
1. Actinocyclus Ehrenbergii	N?					—	—	—	—												6															•	•	•							1			
2. Actinocyclus Ehrenbergii var. tenella					—	—	—	—	—				4					1	1							3										1		1	2	2			2			1		
3. Actinocyclus ellipticus var. javanica						—				2							•		•		2	2					•	•																				1
4. Actinocyclus ingens						—						1	25	12	9	15	12	3	11	20	1	1	3			•	2	7	12		•	•	1			20	15	12	20	15	12	10	9	•		•	1	•
5. Actinocyclus tsugaruensis, n. sp.										4	2	15	12	12	9	15	5	3	12	5	1	2	1			1	7	3	3							2	2	7		25	2	•	2				2	
6. Actinoptychus senarius					—	—	—	—	—	11	11	1	5	5	14	6	34	12	13	10	1	7	5	11	3	20	6	2	3		10	15	6			6	60	6	3	3	19	4	8	1	6	5	12	20
7. Actinoptychus splendens var. Halionyx						—																																					•					
8. Arachnoidiscus Ehrenbergii	S					—	—	—	—																					2		1		•			1			1	•		•	2	•	•	1	
9. Asterompholus moronensis						—									2	1	•	1	1	1											•							13	1									1
10. Aulacodiscus amoenus var. hungaricus	S?					—																																					•				1	
11. Cladogramma californicum						—										1	1									1																	•					
12. Cocconeis antiqua	S?					?																			1	1			•	1	1	1						1					•	•	•			
13. Cocconeis curvirotunda	S					?+			—																					•	2	•	•						•					•	•	1		1
14. Cocconeis formosa	S?					+											1		1					1	1	2				4	1	3																
15. Cocconeis vitrea	S					—			—																				•																			
16. Coscinodiscus argus	O				—	—	—	—	—	4	12	1	1		2	1	1	1	6	8	4	3				•	1	1	1							2	1			1		1	3	1	6			1
17. Coscinodiscus curvatulus var. odontodiscus	N					—			—	1	1							•			2		1		1	1	1	1	2		2		2				1	2		2								
18. Coscinodiscus elegans						—				2		1	2	1		3				2			•				•	2	•	2	2					3	3	•	2	5	3	4	51	3	2			1
19. Coscinodiscus Endoi, n. sp.										1	1			8	24	7	5	5	12			1	5				1		6	2			2			24	10	17	5	5	16	12						
20. Coscinodiscus excentricus			—	—	—	—	—	—	—										1	12	1				3					2	2		1						1					3	2			
21. Coscinodiscus hirosakiensis, n. sp.										1			1			5			1	2	2		2		1		3		•	3	2					1				2		•	1	1	2			
22. Coscinodiscus lineatus	O		—	—	—	—	—	—	—			1				•	1	1		1	1	1				2					1	1												3	1	2		
23. Coscinodiscus marginatus	O		—	—	—	—	—	—	—	19	18	22	33	11		4	3	1	11	1		•	1	168	10	45	2	1	1	86	80	54	131	192					1	3	4	1	13	65	22	35	46	32
24. Coscinodiscus oculus-iridis	O				—	—	—	—	—	1		1			2	1	4		2	2	3						1			2			2			1								4	1			
25. Coscinodiscus radiatus	O				—	—	—	—	—			3	3	1	5		6	1	5	1		2		1	1		3	1		4								1	1	2			2	4	2		1	
26. Coscinodiscus Rothii	N				—				—												2								1		1		2												1			
27. Coscinodiscus Temperi						?							•					1												•			2										•	2				
28. Coscinodiscus vetustissimus						—	—		?	4	1	1	1	•	1	•	•	1	•		11	1	5			5	12		2							6	1		9	19	3		3		1		1	1
29. Coscinodiscus Yabei, n. sp.														2	7	10	2	3	•	•	12		7					6	3							6	4	10	1	1	3	5						
30. Denticula lauta	O					—		—	—	23	25	10	52	33	22	48	58	123	10	58	28	46	17		56	23	29	41	27	5	14	3				19	38	45	43	28	54	42	11	1			1	2
31. Denticula ? sp.												64	28	23									•						2							3					29	17			3		1	
32. Dicladia capreolus						—				1			1				2	1	1			•		2					•												•			1	1			
33. Endictya japonica, n. sp.																			2		1	•		1			•			3		1	2										1	2				1
34. Fragilaria hirosakiensis, n. sp.										94	90	26	7	35	53	26	13	15	21	22	22	78	132	2	42	34	101	92	108	33	54	75	15			33	17	25	64	28	30	46	9	8	24	130	46	50
35. Grammatophora spp.	S?									1		1	1	1					•						1				3	2	1			2								•	5	8	1	1	4	3
36. Melosira granulata	F					—	—	—	—								1		2						3	1					1									2		2			2	2	2	
37. Melosira sol	S?					—			—							1			2					1	2	3			•		•							1					4	4	1		2	3
38. Melosira sulcata	S				—	—	—	—	—	5	14	2	1		3	3	1				1	1			4	3		2	1		1	3	3	4		6	3	1		6		2	11	5	20	1	9	3
39. Rhizosolenia spp.										1		2	3	9	17	14	15	1	15	13	5	5	1		3	10	2	6	2		6	2	13				10	6	28	20	10	16	7				5	1
40. Rouxia Peragalli						?					1				3			1	1		9				1		1	4	1			1				11					3	6					13	39
41. Rutilaria epsilon						—																				•												•					•					
42. Stephanogonia Hanzawae, n. sp.											1	4	1	•	3	4	2	3	3	•			12				2	4	2							2	•	3		•	•	•		•				
43. Stephanopyxis cfr. ferox				—							2	1	•	4	3	3	4	4	6	3	•	1	•	1			1			3	•		•			1	5	2	1	1	•	1	1					
44. Stephanopyxis cfr. nipponica	N								—	1				1												3						1				•												

45. Stephanopyxis Schenckii, n. sp.										1	2		•	1	2	1		1	2	1		•					•	2								1	•			•		1	•					
46. Stephanopyxis turris	N?			—	—	—	—	—	—			1	1	1	•			2			1		2			2	1									5	1			2		1	•	35	24		1	
47. Stephanopyxis ? limbata var. Crista-galli						?									•		•																															
48. Thalassiosira decipiens	N			-					—		5								1		•				•	6		•		7	2		5									1		4	26	1		2
49. Thalassiothrix longissima	O					—	—	—	—	11	6	7	2	10	3	3	2	1	12	14	50	39	4	1	3	20	13	16	11	8	9	10	4			2	1	5	3	2	5			1	1	4	10	15
50. Triceratium sp. α															3												1	1									1											
51. Triceratium sp. β																					•								•																			
52. Xanthiopyxis acrolopha																					•		•																									
53. Xanthiopyxis spp.										4	4	21	11	9	8	9	15	6	13	2	10	1	1	1	11	4	5	6	1	6	5		1			18	9	16	4	16	4	3	8			3	1	1
Total number in N=200										192	196	186	195	179	195	181	188	192	168	178	176	191	199	190	175	190	195	198	192	175	197	171	192	198		172	183	175	189	191	197	175	157	158	150	186	160	178
Miscellanea										8	4	14	5	21	5	19	12	8	32	22	24	9	1	10	25	10	5	2	8	25	3	29	8	2		28	17	25	11	9	3	25	49	42	50	14	40	22
Number of sublittoral+neritic species:number of species appeared										4/21	4/17	4/21	5/24	4/21	3/23	3/24	2/26	4/25	7/32	1/21	9/27	2/20	3/20	3/11	8/19	10/24	3/25	4/21	10/27	4/20	10/24	7/16	6/18	3/4		6/24	6/22	7/22	2/17	7/26	3/19	6/23	13/28	9/25	11/25	7/14	7/20	6/19
Number of oceanic species: number of species appered										5/21	4/17	7/21	5/24	4/21	5/23	6/24	7/26	6/25	6/32	7/21	5/27	6/20	3/20	3/11	4/19	5/24	6/25	5/21	4/27	6/20	4/24	4/16	3/18	1/4		4/24	3/22	2/22	3/17	4/26	3/19	3/23	3/28	6/25	5/25	3/14	3/20	4/19
Number of sublittoral+neritic individuals (valves) in 200										19	31	5	12	7	17	10	35	15	23	10	13	8	8	13	13	44	8	5	6	14	19	21	10	6		27	66	12	5	16	19	6	30	59	80	9	30	32
Number of oceanic individuals (valves) in 200										58	61	45	91	55	34	57	75	128	46	85	86	91	22	169	98	90	49	59	40	101	104	68	135	192		24	40	50	47	34	63	44	27	75	31	41	57	50



EXPLANATION OF
ECOLOGICAL REMARKS (FROM JOUSÉ,1957)

S: SUBLITTORAL

N: NERITIC

O: OCEANIC

F: FRESHWATER

AN INTEROGATION MARK INDICATES THAT THE ASSIGMENT IS INFERRED FROM ALLIED FORMS

Liradiscus sp.
small *Navicula* spp.
Nitzschia ? *marina* Grun.
Pterotheca spada Temp. and Brun
Stephanodiscus sp.

None of the above-mentioned forms showed occurrences bearing particular importance in the present analysis. The second group inculdes:

Cocconeis scutellum Ehr.
Navicula adonis Brun
Stephanopyxis with fine areoleae
Stictodiscus cfr. *argus* Schmidt
Thalassiosira Usatchevii Jousé (Jousé, 1957, pl. 5, figs. 16, 18)
Thalassiosira Zabelinae Jousé (*ibid*, pl. 5, fig. 15)
large *Triceratium*, *Triceratium favus* Ehr. type
Triceratium radians forma *quadrata* Brun

Thalassiosira Usatchevii, and *Th. Zabelinae*, both reported by Jousé (1957) as Pliocene species transported to the bottom surface sediments of the Sea of Okhotsk, are of particular importance, since they were observed to appear, though very rarely, in the assemblage C in the Onnagawa formation, where the elements which mark the lower two assemblages, the assmblages A, and B (=*Conscinodiscus Yabei* assemblage), practically disappear. While examining the late Miocene and Pliocene samples from Northern Japan, the writer has met in several occasions, *Thalassiosira Usatchevii* showing rather high frequencies enough to be called a frequent species as it was in the two samples of the Maido formation here incorporated.

Two groups are not distinguished in the chart. It can be said that the forms of the second group take more part in numbers, of the miscellanea in the samples from the Assemblage C in the Onnagawa formation, in the sample from the uppermost part of the Owasawa formation (Ao–13), and those five samples from the higher horizons.

The small solid circle given in the column indicates that the species did not appear in the 200 specimens counted, but was found present while examining the entire field of two strewn slides prepared from the sample.

The relative diatom density in the samples are shown by the diagram along the base of the distribution chart. They are indicated by reciprocals of the number of the unit areas required to obtain 200 diatom valves by the procedure described in Chapter II. Hence, if five unit areas were required to obtain 200 spesimens on a strewn slide of a sample, the relative density of the sample is 1/3.

As it is obvious from the cleaning procedure, the diatom density thus obtained reflect the density of diatom valves in the cleaned final residue, but not in the original rock. The final residue was obtained, as was mentioned, by removing of the original rock (1) acid soluable consititutents by the acid treatment; and (2) insoluble grains having smaller or greater quantity of hydrolic diameters than that of the diatoms by floatation and settling in distilled water. Thus the relative diatom density in the series of the washed samples only reflect the diatom densities in the original rocks, when the original rocks being compared are not greatly different in carbonate contents, and in texture. Most of the samples in the present study fall within the texture of mudstone consisting of silt and clay sized grains, and the rest are fine grained sandy mudstone. None of them are limy; and all of them are practically barren of foraminifera and woody fragments. Hence, it is judged that, the samples warrants the application of the relative diatom density to compare, in relative manner, the diatom contents of the samples.

The ecological behaviour of species in terms of marine environment are indicated as was assigned by Jousé (1957), and the known stratigraphic ranges of the species are drawn on the basis of the previous records, which are remarked in the systematic part of the present paper (Chapter IV) following the description of each species.

Stratigraphic Ranges of Species and Previous Records

The stratigraphic ranges of the species are compiled in the column at the left of the distribution chart (Chart 6). For informations on which this compilation is based, the readers are referred to the notes following the systematic description of each species. To draw reliable stratigraphic ranges for the species on the basis of their previous records of occurrences, age determination of the material dealt with in the previous works must be carefully revised in terms of the current stratigraphic knowledge and terminology.

The previous works which were selected to be reliable for the purpose through such a revision were once listed by the present writer (Kanaya, 1957, pp. 49–55). To them, the following works are added to be incorporated in the determination of the ranges of the species found in the Japanese Miocene material.

PANTOCSEK, J., 1903, *Beiträge zur Kenntniss der fossilen Bacillarien Ungarn.* Remarks on ages given by Pia (in Hirmer, 1927, p. 46) of the following Pantocsek's localities are accepted.

"Szent Peter", "Szakal," "Nagy-Kurtos" in Hungary: Miocene, Helvetian Stage, according to Forti, middle Miocene.

"Dolje" in Croatia: Sarmatian Stage, upper Miocene

"Elese," "Bory" in Hungary: Pontian Stage, lower Pliocene.

All Pantocsek's Japanese localities, are of Hokkaido, Japan, but the present writer fails to add any stratigraphic information with certainty.

"Wembetsu" should be written as "Enbetsu" by the current usage, and the part where the diatomaceous material was collected belong to the [early] Pliocene Enbetsu Group, [formation], according to Okuno (1952, p. 5, and p. 33). The present writer tentatively follows this.

"Teshigori" should be Teshio-gun (gun is a subdivision of province in Hokkaido), and the "Enbetsu" locality belongs to the same province. The source of this material should be in the same area, and the most probable source seems to be the Koitoi formation which is known to contain diatomite.

"Abashiri" was collected at near Abashiri lake (Sato, 1911, p. 15). The most probable source of the material is the Yobito formation, early Pliocene in age.

Correlation of the above-mentioned formations of the Tertiary section in Hokkaido has recently become a subject of intense discussion (Uozumi *et al.*, 1958; Hashimoto, 1958), and one can not be certain of whether the distomaceous material came from late Miocene or each Pliocene parts, unless the exact locality is known. Therefore, the age assignment given are only tentative.

ICHIKAWA, W., 1950, *The correlation of the Diatom-bearing Mudstone in Noto Peninsula and the vicinity of Kanazawa City* (in Japanese with an abstract in English).

The occurrences of 78 species and varieties of 34 genera identified in samples from six formations developed in the area of Noto Peninsula, and the vicinity of Kanazawa City were summarized in a table. The formations are: Iizume formation, Tsukuda mudstone, Wakura formation; Hijirikawa mudstone, Mitsukoji mudstone, and the Yamatoda mudstone. He concluded that, except the Yamatoda mudstone, which is of fresh-water origin, they are marine sediments, and all of the formations are in the same geological horizon "somewhere in the late Miocene or early Pliocene" (*op. cit.*, p. 56).

Later, Suzuki (1950, p. 136) who supplied some of the samples Ichikawa studied, as well as the stratigraphic informations for their correlation, revised his former view, and explained the stratigraphic relations of the diatomaceous mudstone of Noto Peninsula as follows:

Group	Formation	Member	
Yokawa	Yoshitaki	* Hijirikawa mudstone	Awahara mudstone
	Nanao	* Wakura mudstone	* Yamatoda mudstone
Noto	Fugeshi	* Iizuka mudstone	
	Minatsuki	Iida tuffaceous mudstone * Tsukada mudstone Usetsu	

* indicating the diatomaceous mudstone dealt with Ichikawa.

Still later Suzuki (1953)[1] expresed his veiw of assigning the stratigraphic positions of these formations in terms of the letter nomination proposed by Ikebe (1954) to apply for the Cenozoic formations of Japan. According to Suzuki, the Minatsuki formation is F, and the Fugeshi, Nanao, and Yoshitaki formations are G. Ikebe considers (1954, p. 78) his F_1 the Lower Miocene; F_{2-3} the Middle Miocene; and G as the Upper Miocene or Lower Pliocene, where the Onnagawa formation, which is considered as of the middle (or medial) Miocene in the present paper, is F_3. The Funakawa formation, which is, in the present paper, of the upper Miocene together with the Kitaura, takes the upper part of F_3 and the entire G in Ikebe's scheme.

Ichikawa's conclusion that his samples are of "late Miocene or early Pliocene" apparently resulted by referring all his samples to G of the Letter nomination, which Suzuki considered otherwise. What is implied by Suzuki's table is that the diatomaceous rocks in the area distribute in sequence with wider vertical range than was stated by Ichikawa. Preliminary examination of Ichikawa's samples[2]; suggests that the diatom flora contained seems also in support this.

Due to the above-mentioned reason, the writer believes that it is best, at least at present, to refer Ichikawa's samples to the Miocene, without specifying whether they belong to the upper or middle part of the series. There is no possibility, from the stratigraphy of the area, that the samples should belong to the early Miocene.

It is unfortunate that Brun and Tempère's well-known paper entitled "*Diatomées Fossiles de Japon*" must be omitted from the stratigraphic discussion of the species, since neither localities, nor geologic ages of their samples have been yet ascertained. The paper is very important taxonomically, but the information about their source leaves only ample clue for search.

According to them the Sendai sample was a fragment of bituminous limestone send by a missionary from Sendai; and Yedo samples are small pebbles of bituminous limestone found in the bottom sediments collected by Prof. Appert from "Yedo Bay" which is the Tokyo Bay.

Preservation of diatoms in the bituminous limestones seems to have been remarkably well. By treating the rocks with acid, they succeeded to have separated many perfectly preserved diatom valves. The assemblage they found are peculiar and large : they identified 129 species and 60 varieties of 47 genera, besides describing as many as 118 new species and 9 varieties of 46 genera, including one new genus. The samples from the two sources contain large numbers of species common to

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1) At a lecture presented before the symposium of the Green-tuff problem of Japan, held in April, in Tokyo.

2) Dr. Ichikawa kindly placed his original rock samples at the writer's disposal.

both.

In Sendai and its environs whose geology has long been studied, no Tertiary formation bearing limestone strata has ever been reported. The oldest Tertiary marine rocks in the area is of the early Miocene (Moniwa formation, Hanzawa et al, 1953). There are formations partly diatomaceous (*ibid.*, p. 17, p. 22, p. 24), but the assemblages contained are not be comparable with those described by Brun and Tempère in number of species and in their peculiarities. No Paleogene nor Cretaceous formations are known to outcrop in Sendai and its environs. Several carbonate concretion from the Miocene and Pliocene rocks of the area were dissolved in acid ; but with no trace of diatoms.

As will be mentioned later, a few of Brun and Tempère's species previously known only by the type material was found, though rarely, in the middle and upper Miocene materials examined for the study. This seems to promise the findings of the species in the classic paper, should studies on the late Miocene and Pliocene rocks of northern Japan be extended. Exceptional richness of Brun and Tempère's assemblage is undoubtedly because, as they suggested, the diatom cells were fossilized by lime, before the solution of silica had been effected.

Concerning the "Yedo" samples, the present writer admits, judging from the geology of the tributary area of Tokyo Bay, that there is no known probable late Cretaceous nor Paleogene sources for the material.

Paleoecological Interpretations

The difficulties relating to the paleoecological analysis of fossil diatom assemblages were once outlined by the present writer (Kanaya, 1957, pp. 48–49). They are in short (1) lack of knowledge on spacial as well as compositional relations between biocoenose and thanatocoenose of diatoms; (2) the scarcity of "indicator species" of living plankton communities preservable in the bottom sediments, and/or the scarcity of preservable species whose ecological behaviors are known; and (3) decrease in fossil assemblages percentage of living species on which the paleoecological inferences should be based, with the geologic ages of the assemblages.

The statements hold true for the paleoecological interpretations of the present material, Japanese middle Miocene marine assemblages : the second reason, above mentioned, limits the application of the excellent work by Aikawa (1936) concerning the living diatom communities in the waters surrounding Japan to the present analysis. The first cited defiiciencies, however, was materially removed by the studies of diatoms in the bottom surface sediments of the Sea of Okhotsk recently published by Jousé (1957).

Studying the bottom surface samples from 183 stations of the Sea of Okhotsk, Jousé identified 206 diatom species and varieties of 63 genera, including five species which she believed to be Pliocene ones. On the basis of accumulated knowledge concerning the distribution of living diatoms in the Sea of Okhotsk and of the Bering Sea, she grouped the identified species into several ecological categories. In terms of type of water they inhabit, the species were divided into freshwater, Euryhaline, and marine; in terms of their mode of life, planktonic and benthonic; with regards to the marine environment sublittoral, neritic and oceanic; and by temperature the species were assigned to be of arctic, arctoboreal, boreal cold, boreal warm.

Among them, the sublittoral-neritic-oceanic subdivision has a direct bearing on the present discussion.

Jousé summarized the distribution of the diatom species in the bottom surface layer of the area and concluded that the distribution warrants the recognition of three zones, each of which is characterized by their proportions of neritic, and oceanic species in species number. The zones are (Jousé, ibid. p. 210) : (1) the neritic zone where the neritic species take 70–100 percent of the assemblage in the bottom surface sediments ; (2) the oceanic zone, where the oceanic species takes 70–100 percent of the assemblages in the bottom surface sediments; and (3) the mixed zone, where the neritic and oceanic species divide the assemblage in the bottom surface layer in similar proportions. The entire area of the Sea of Okhotsk was mapped by the zones (Jousé, 1957, pl. 6), and the bathymetric distribution of the zones in the area were stated as follows :

Neritic zone - usually not extending beyond the 200 meters depth line; extends to 300–400 m depth off South Sakhalin, and off the west coast of Kamtchatka.

Oceanic zone- mainly in the central portion of the sea, ranging 1000–3000 m in depth.

Mixed zone - wide in the northern part of the sea, 300–700 m in depth, 900 m in the Tinro Basin : 200–700 m in depth off Sakhalin; wide in the area off Hokkaido where it extends to the depth of 3000 m; and narrow along off Kamchatka.

Very important is Jousé's mentioning that the distribution of the recognized zones of diatom thanatocoenose shows a close correlation with that of living plankton population (biocoenose) of the surface waters, except that such feature as the mixed zone does not exist in the living population; and it is on the continental slope where the correlation is found disturbed. The result obtained furnishes a logical foundation to warrant paleoecological interpretation of diatom thanatocoenose in terms of an ecological aspect of the contained species.

It appears that an analogy can not be drawn between the process of accumulation of diatom cells on the bottom surface layer of an inland sea like the Okhotsk, and that of the diatom assemblages on the bottom of large ocean basins like the Pacific and the Atlantic where the dead diatom cells should travel greater distances to finally come to rest on the ocean to bottoms. The result obtained by Lohman from the analysis of the North Atlantic deep-sea cores (Lohman, 1941, p. 59) indicated this.

On the other hand, it can be inferred that the similar mechanism of accumulation may have prevailed while Miocene and Pliocene fine clastic rocks, now exposed along the Japan Sea side of northern Honshu, were being formed, since stratigraphers (Kitamura, 1958 a) now have sufficient evidence to draw a paleogeographic map showing that the area in which these strata accummulated were then inland seas.

Difficulty remains concerning the ecological analysis of the present material because of the scarcity of ecologically known species in the fossil assemblages.

As shown in the column attached to the distribution chart (Chart 6), out of 50 species and varieties identified in the present material 27 are extinct and have no living counterparts. Available species for the present purpose are selected by accepting Jousé's terms of the sublittoral-neritic-oceanic categories[3].

The forms available for the analysis are only 25, even including eight fossil species whose habitates were inferred from their living allies listed by Jousé. Thus one half of the elements of the middle Miocene assemblages still remain undetermined so far as their habitate is concerned. In a few samples, the ecologically known forms number more than half of the distinguishable ones in a sample, but are usually less, as are shown in the bottom rows of the distribution chart (Chart 6).

Frequencies of each ecology group, given in the bottom two rows of the distribution chart, show that such statistics may not be dependable in the present case. Of three of the dominant species, *Coscinodiscus marginatus*, and *Denticula lauta* Bail. (as *Denticula marina* Semina) are oceanic according to Jousé. The remaining one, *Fragilaria hirosakiensis* Kanaya, n. sp., which sometimes takes more than half of the assemblage in number, is a new species, therefore ecologically undeterminable, and is not incorporative to the analysis. Consequently, the conclusion drawn from an analysis with the dominant species ecologically unkown, may be upset, when the ecology of the species becomes known by future work, and thus becomes incorporative to the analysis.

Pyxilleae whose mother species are not determinable, and undetermined fragmental *Rhizosolenia* amount to 12 forms in the present material, and it is these genera towhich the well known indicator species of currents or living diatom communities belong. If these forms are correctly identified, the situation will be much improved.

Thus, from the available data, only broad inferences can be drawn about the

3) Her assignment is more clear-cut than that once attempted by Lohman (1941, p. 57). In the present discussion the writer accepts Jousé's view to preservé the unity of data on which the assignment was based.

environment in which the diatom assemblages of the Onnagawa formation accummulated.

1. Comparisons with the diatom thanatocoenoses of the enclosed bays of Japan studied by Oshite (the Mutsu, Uranouchi, and Kurita Bays, 1954, 1955, 1957, respectively), suggest that the environment in which these Miocene diatom thanatocoenoses accumulated were more influenced by ocean waters, and deposition took place in water bodies much larger than those bays. The scarcity of freshwater species (only rare occurences of *Melosira granulata*), and dominancy of open water species (*Denticula lauta*, and *Coscinodiscus marginatus*) indicate this.

2. The environment in which the diatom bearing fine clastic rocks accumulated seems to have been particularly more favorable than usual for diatom reproduction.

According to Jousé (1957, p. 167) the bottom surface sediments of the Sea of Okhotsk contained 250000–500000 diatom cells in 1 g. of dried sediments.

The bottom sediments of Mutsu Bay[4], according to Oshite (1954, p. 207), yielded around 50000 diatom cells in the sandy bottom, and 150000 cells in the muddy bottom, in 1 g. of dried samples, respectively. The maximum figure obtained was 370000 cells per 1 g., and Mutsu Bay contains more diatom cells in its bottom sediments than the two other bays he studied.

A rough estimation[5] shows that out of 25 samples examined for the Onnagawa formation, half of them contains more than 2000000 diatom valves in 1 g. of rock sample; the minimum figure obtained among the samples was 300000, and the maximum was as much as 8000000 valves in 1 g. The figure may be divided by 2 (a diatom cell consist of two valves) to make them comparable with those from the Recent bottom sediments.

Thus, about a half of the Onnagawa samples contain in an unit weight more diatom dead cells than the most diatomaceous part of the Okhotsk Sea bottom; and the least diatomaceous sample of the Onnagawa formation is comparable with the diatom contents of the average muddy bottom of Mutsu Bay.

3. According to Jousé, *Denticula marina* Semina was the qualitatively dominant species in the bottom sediments of the Sea of Okhotsk. Comparison with the illustrations (Jousé, 1957, pl. 4, figs. 16a, 16b) strongly suggests that the species

4) Situated at the northern end of Honshu Island, Japan. 55 km in EW, 40 km in NS, maximum depth 70 m, opens north to the Tsugaru Strait by a mouth 10 km in width. Salinity 33 ‰ at surface, 33.75 ‰ at bottom; surface temperature minimum in February 4°C., maximum in September-October, 23°–24°C.

5) By rough estimation: if half of the weight of the original rock was removed by clearing procedure, and the specific gravity of the final residue is 2.0, approximately 100000 diatom valves 1 g. of original rock is expected when 3 valves are found in 1 unit area of 1/8 unit strewn slide (see Chapter II).

what Jousé calls *Denticula marina* is *Denticula lauta* in the present paper[6]. *Denticula* closely similar to *Denticula lauta* has been known in the Bering waters, as well as in the bottom sediments of the area, and this form and *Denticula* sp. of the Japanese marine biologists seems to be the same species[7] (for detail, see Chart 4, Systematic description of the species).

With regard to the distribution of *Denticula* sp. in living plankton communities, Aikawa (1936) stated that the species is prevalent in the summer Plankton of the sea surrounding the west Aleutian islands, and in the neritic region off Kamtchatka where, for instance, the form was chosen as one of the leading ones and represents a plankton community "*Denticula*" group (Aikawa, ibid., p. 30, 31). The southern limit of its prevalent occurrences in plankton communities is about 40° Lat. N. in the Tohoku region : along the Same Kaku line (Aikawa, 1936, fig. 20, p. 66, off Aomori Pref., appr. 40°20′ Lat. N. parallel, extending east as far as 100 km from the shore), *Denticula* prevails, thongh for only a short period (in April), and quickly becomes replaced by other forms (p. 57), whereas along the On Saki line (fig. 20, p. 66, off Iwate Pref., appr. 39° 40′ Lat. N.) the species never attains so large a percentage as off Aomori Prefecture (p. 57).

Oshite (1954) reported no *Denticula* in his study of the bottom sediments of Mutsu Bay (situated appr. 41° Lat. N.) which, being open to the Tsugaru Strait, recieves considerable influence from the warmer waters flowing from the Japan Sea to the Pacific through the strait.

Judging from the above mentioned evidences, it may be safe to infer that this group of living *Denticula* (*Denticula lauta*, *Denticula marina*, and *Denticula* sp.) is an element of cold waters which flows from the sub-arctic Pacific to the Tohoku region, and in this respect, the high frequenices of *Denticula lauta* in the Onnagawa formation samples are noteworthy.

As it was mentioned in the previous chapter (Chapter I), in Oga Peninsula, the Nishikurosawa formation conformably underlies the Hirasawa diatomaceous mudstone member (of the Onnagawa formation) which contains *Denticula lauta* abundantly (see Charts 6, and 7). From a well known *Miogypsina-Operculina* foraminiferal assemblage of the Nishikurosawa formation, which is believed to be subtropical, this diatomaceous mudstone is within a thickness of only 15 m. If the assumption that the above mentioned *Denticula* is a cold water element is correct,

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6) Dr. A. Jousé kindly provided the writer with a photomicrograph of *Denticula marina* Semina from the Okhotsk Sea bottom. The picture confirms the present comparison.

7) The writer had an opportunity at The Scripps Institution of Oceanography to compare the Bering water form prepared by Dr. R. Holmes of the institution, and Japanese form sent by Dr. S. Motoda to Dr. Holmes. A study about the physical properties and distribution of water mass to which *Denticula* is restricted in now being progressed by Dr. Holmes at Scripps.

and if the ecological adjustment of organisms was essentially similar during the past geological epochs as it is usually assumed so, the change in water temperature which took place between this 15 m of clastic rocks was significant.

One may further notice, from Chart 6 and Chart 7, that the high frequencies of *Denticula lauta* prevail in the assemblages of the Onnagawa and its equivalent formations; whereas the species is scarce in the samples of the higher horizons, which are referred in the present paper to the late Miocene in age. The higher horizons being referred correspond to the horizons of "F" (of Funakawa and its correlatives), and and "K" (of the Kitaura and its correlatives), proposed by Kotaka (1957, p. 41; 1958, p. 54) on the basis of the molluscan fauna. The molluscan fauna of the formations correlative with the Onnagawa corresponds to "O". Kotaka concluded (1958, p. 56) that it was during "F" time (not during "O", as is inferred from *Denticula lauta*), when the temperate-cool fauna invaded Northeast Japan and replaced the preceeding fauna of "O", which is transitional from the subtropical Nishikurosawa fauna.

The difference seems as if confliciting at first glance, but this can be explained as follows. The molluscan fauna Kotaka dealt with are near shore or more shoreward inhabitants than the diatom plankton communities, and the diatomaceous rocks accumulated in the bottom more distant from the shore than those yielding the molluscan remains. The Onnagawa formation is very scanty in molluscan remains in the Oga Peninsula, and the "*Pecten*" fauna of "O", which is the survival of the subtropical Nishikurosawa fauna, has usually been found from more shoreward localities[8] than the diatomaceous rocks in Oga Peninsula with regard to the ancient shoreline drawn by Kitamura (1958, p. 11, fig. III) for the time, which is the stage III of Kitamura (Fig. 2 in the present paper). Therefore, the appearance of the diatom assemblages of the Onnagawa formation containing the cold water element can be explained as it indicates an event, that is, an invasion of the cold current into the off shore part of the subsiding geosynclinal area where warmer waters had been prevailing, and thus permitted warmer molluscan fauna to have populated in the shoreward part of the sea.

One point is open to question : if *D. lauta* was a cold water species as is inferred, then why did it became scarce in the samples from the formations of the higher horizons. According to the molluscan evidence, the waters may have been cooler and deeper during this time than those which prevailed during the accumulation of the Onnagawa formation.

Assemblages from the Onnagawa Formation

Descriptions of the assemblages

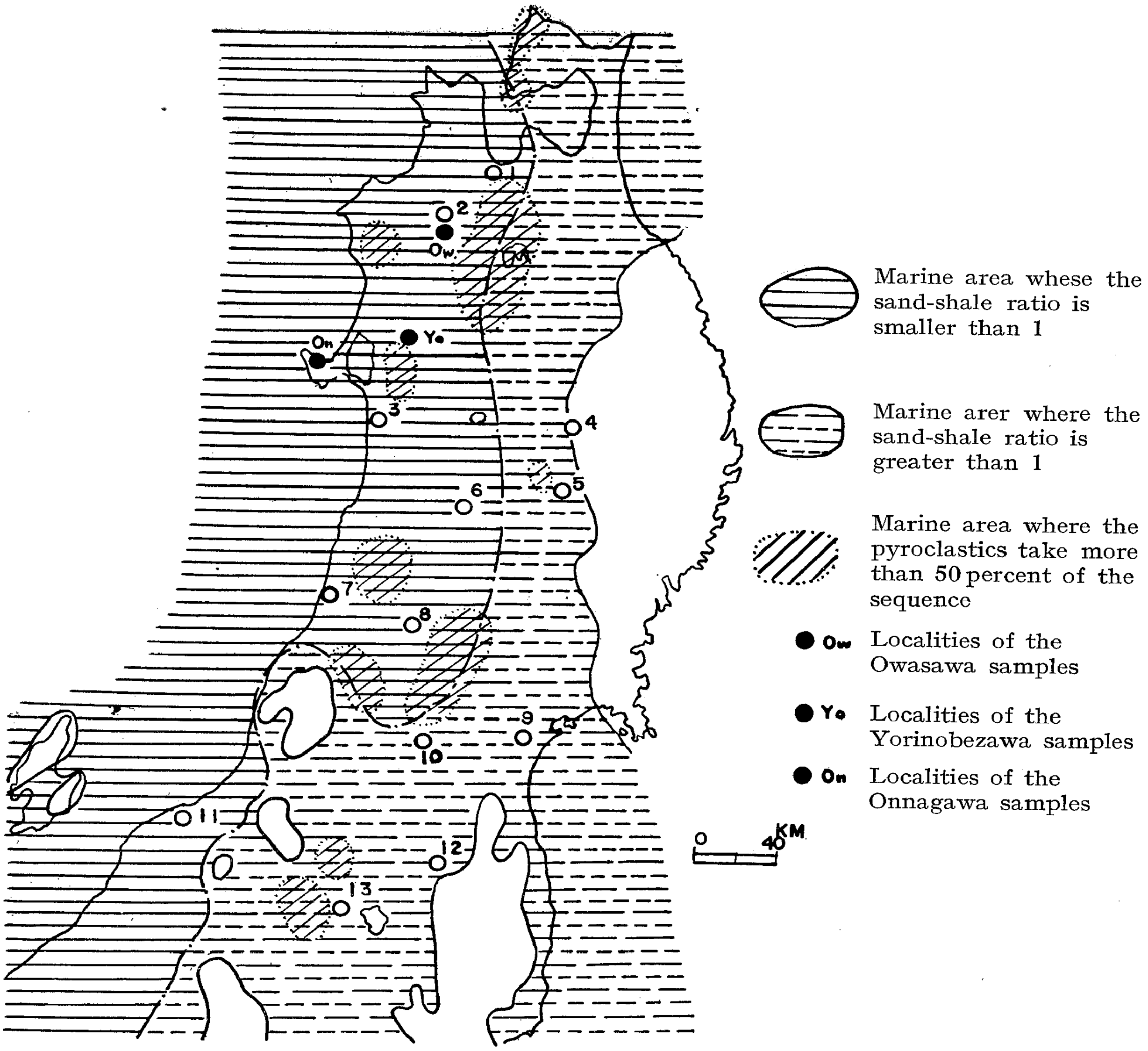
As it was mentioned previously, the present study of the middle Miocene diatom

8) In the areas drawn on Figure 2 as of the sand-shale ratio greater than 1.

Fig. 2

PALEOGEOGRAPHICAL MAP OF NORTHEAST HONSHU STAGE III:

THE STAGE OF ACCUMMULATION OF THE ONNAGAWA AND ITS CORRELATIVE FORMATIONS (AFTER KITAMURA, 1958)



1: Aomori 2: Hirosaki 3: Akita 4: Morioka 5: Hanamaki
6: Yokote 7: Sakata 8: Shinjo 9: Sendai 10: Yamagata
11: Niigata 12: Fukushima 13: Aizuwakamatsu

assemblages was started in 1949 with the examination of the samples from the Owasawa formation, Aomori Prefecture, whose stratigraphic position was then not precisely known. Later, the study was extended to the diatomaceous part of the Onnagawa formation of Oga Peninsula, Akita Prefectuıe where the Miocene and Pliocene marine strata are exposed without stratigraphic break, and therefore, the stratigraphic subdivision established there has long been used as a standard with which the Miocene and Pliocene formations of the Japan Sea coast of northern Japan are correlated. To make biostratigraphic units applicable to the stratigraphic correlation, choosing such an area as the type is most desirable. Hence, the diatom assemblages of the Onnagawa formation are analysed first in this paper with an attempt to establish the units to which the assemblages of the other areas can be compared.

From the Oga sections, rocks which are sufficiently diatomaceous for the present analysis were obtained from the two rock units, Hirasawa diatomaceous mudstone member of the Hirasawa area, and Shinzan diatomaceous mudstone member of the Shinzan area, both of the Onnagawa formation.

With regards to the underlying rock units, the Hirasawa diatomaceous mudstone member seems to be stratigraphically lower than the Shinzan diatomaceous mudstone member, since the former which bears glauconitic shale and mudstone of a few meters thick at its base, directly overlies the Nishikurosawa formation conformably (see Chart 2) ; whereas below the latter in the Shinzan area there exists a 50–80 m thick shale and mudstone between the underlying Nishikurosawa formation (see Chart 3). The relation of the two diatomaceous mudstone members, however, can not be ascertained in the field, since the Hirasawa and Shinzan areas are separated by a fault.

Nine samples from the Hirasawa diatomaceous mudstone member, and 16 from the Shinzan diatomaceous mudstone member were examined for the present study. Their localities and stratigaphic positions are given in Chart 2 and Chart 3 ; the distribution of the species found in the examined samples are shown in the distribution chart (Chart 6) in terms of the observed frequencies by a single random count of 200 specimens for each sample, as was explained in Chapter II. The stratigraphic ranges are also given in the chart, and the relative density of diatom in the samples can be read from the diagrams attached to the distribution chart.

First, the experience lead the writer to recognize species which determined the paleobotanical aspect of the diatom assemblages of the Onnagawa formation as a whole, which may be teımed as elements characterizing the fossil diatom flora of the Onnagawa formation.

They are: *Actinocyclus ellipticus* var. *javanica* Reinhold

Actinocyclus ingens Grev.
Actinocyclus tsugaruensis Kanaya, n. sp.
Asteromphalus moronensis (Grev.) Ratt.
Cocconeis antiqua Temp. and Brun
+*Cocconeis curvirotunda* Temp. and Brun
Cocconeis formosa Brun
+*Cocconeis vitrea* Brun
Coscinodiscus Endoi Kanaya, n. sp.
*+*Coscinodiscus marginatus* Ehr.
Coscinodiscus Temperi Brun.
Coscinodiscus vetustissimus Pant.
Coscinodiscus Yabei Kanaya, n. sp.
*+*Denticula lauta* Bail.
**Fragilaria hirosakiensis* Kanaya, n. sp.
Rouxia Peragalli Brun and Herib.
Rutilaria espilon Grev.
Stephanogonia Hanzawae Kanaya, n. sp.
Stephanopyxis cfr. *ferox* (Grev.) Ralfs
Stephanopyxis Schenckii, Kanaya, n. sp.
Stephanopyxis ? limbata var. *Crista-galli* Temp. and Brun
Triceratium sp. α
Triceratium sp. β

The astrisked species frequently dominate over the other elements, in numbers, 1/4 to 1/2, and even more than 3/4 of the diatom contents of a sample. Unless marked by+, the species are extinct, having no previous records from the Recent sea bottom or as of living in the present seas. With regard to their mode of occurrences in the Onnagawa samples shown by the observed frequencies, the above mentioned elements can be classified into three groups.

I. Species showing a high fluctuation in frequencies, ranging from very rare to dominant.

Conscinodiscus marginatus
Denticula lauta
Fragilaria hirosakiensis, Kanaya, n. sp.

II. Species occuring with lower frequencies, but are consistent enough and/or specific throughout the sequences to be representative.

Actinocyclus ingens
Actinocyclus tsugaruensis Kanaya, n. sp.
Cocconeis antiqua
Cocconeis formosa
Coscinodiscus Endoi Kanaya, n. sp.
Coscinodiscus vetustissimus
Coscinodiscus Yabei Kanaya, n. sp.
Rouxia Peragalli
Stephanogonia Hanzawae Kanaya, n. sp.

Stephanopyxis cfr. *ferox*
Stephanopyxis Schenckii Kanaya, n. sp.

III. The rest are the species whose occurrence are paleobotanically important, but are too low and sporadical for making the species dependable for the present analysis.

As was mentioned everywhere in this paper, frequencies shown in the distribution chart, and on which the present analysis depends, are observed frequencies obtained by a single count of 200 specimens for a sample. The counting was assumed to have been random. Therefore, the comparisons of frequencies thus obtained are only reliable when it is inferred so statistically by the limits of expectation of events corresponding to the observed frequencies.

This limits of expectation of an event (occurrences of a species this time) corresponding to the observed frequencies taken from a random sample of 200 specimens were once drawn by the writer (Kanaya, 1957, Chart IV). Statistical reasoning for the construction of the diagram, and statistical inferences which can be drawn from the diagram by the comparisons of the observed frequencies, were also outlined in the paper (Kanaya, ibid., pp. 58–62).

With the ranges of expectations in mind, the distribution chart was consulted in an attempt to recognize the assemblages by which the distribution of the diatoms in the Onnagawa formation can be reasonably grouped.

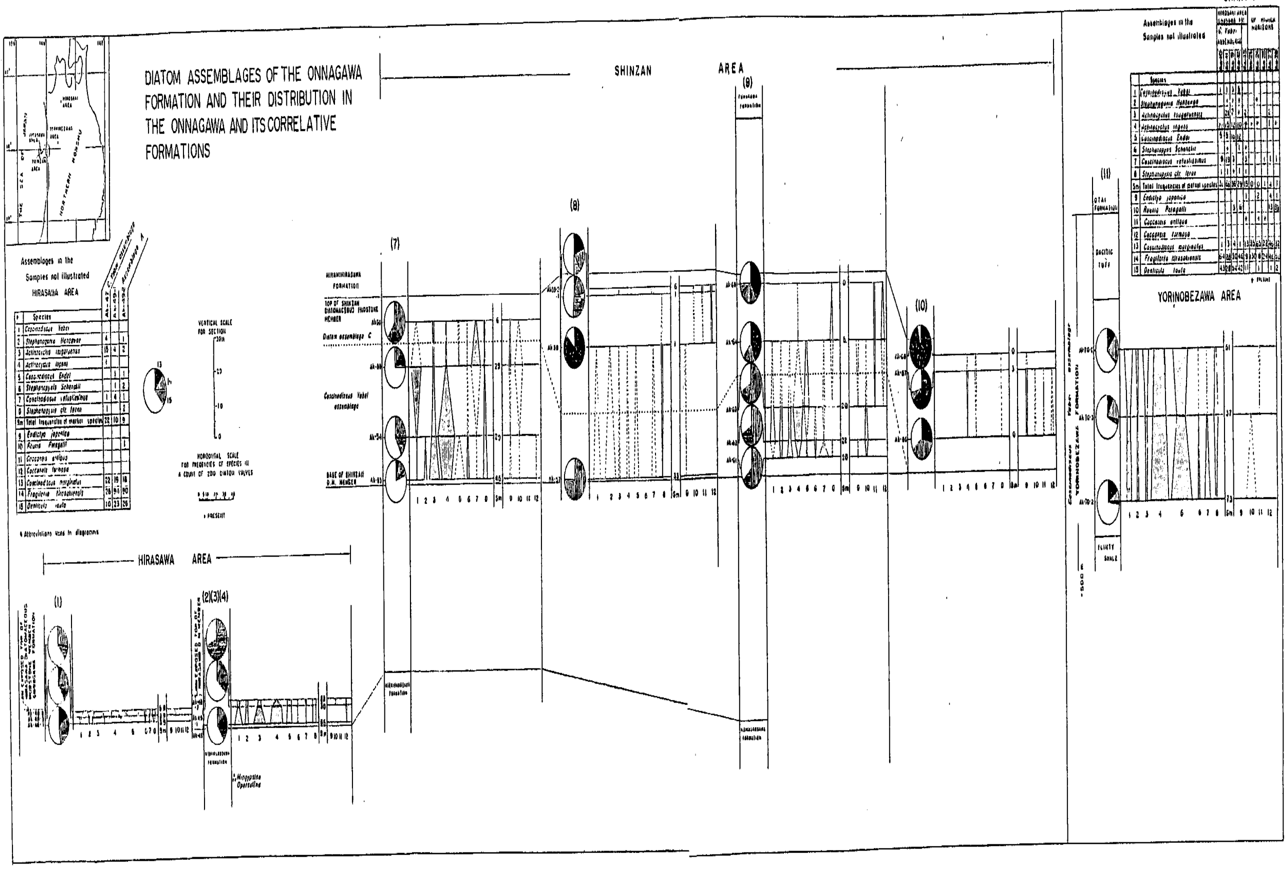
First, the species of the first group were found to be not useful for the analysis. They are the elements which dominate in individual number in many samples, but the fluctuations of frequencies are too sporadical, and inconsistent, to draw any generalization for their occurrences with regard to the positions in a stratigraphic sequence.

The third group appears to be useless for the present analysis, since their occurrences are too sporadical, and frequencies are too low for the purpose.

The species of the second group, however, proved to be useful: if the following eight species are chosen as markers, the distribution of diatoms in the Onnagawa formation represented by 25 samples examined can be grouped into three assemblages, the diatom assemblages A, B (=*Coscinodiscus Yabei* assemblage), and C, as are shown in Chart 7.

The marker species are:

Actinocyclus tsugaruensis Kanaya, n. sp.
Actinocyclus ingens Grev.
Coscinodiscus Endoi Kanaya, n. sp.
Coscinodiscus vetustissimus Pant.
Coscinodiscus Yabei Kanaya, n. sp.
Stephanogonia Hanzawae Kanaya, n. sp.
Stephanopyxis cfr. *ferox* (Grev.) Ralfs


DIATOM ASSEMBLAGES OF THE ONNAGAWA FORMATION AND THEIR DISTRIBUTION IN THE ONNAGAWA AND ITS CORRELATIVE FORMATIONS
SHINZAN AREA
HIRASAWA AREA
YORINOBEZAWA AREA
Assemblages in the Samples not illustrated
HIRASAWA AREA
Species
Total frequencies of marker species
* Abbreviations used in diagrams
VERTICAL SCALE FOR SECTION
HORIZONTAL SCALE FOR FREQUENCIES OF SPECIES IN A COUNT OF 200 DIATOM VALVES
(1)
(2)(3)(4)
(7)
(8)
(9)
(10)
(11)
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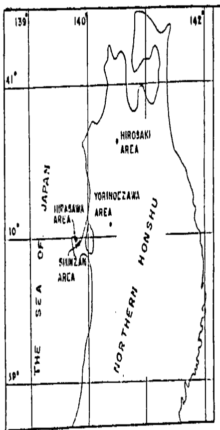


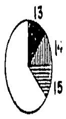
DIATOM ASSEMBLAGES OF THE ONNAGAWA FORMATION AND THEIR DISTRIBUTION IN THE ONNAGAWA AND ITS CORRELATIVE FORMATIONS

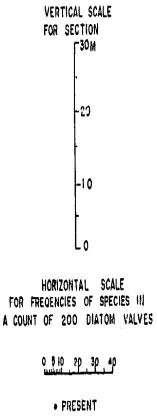
Assemblages in the Samples not illustrated

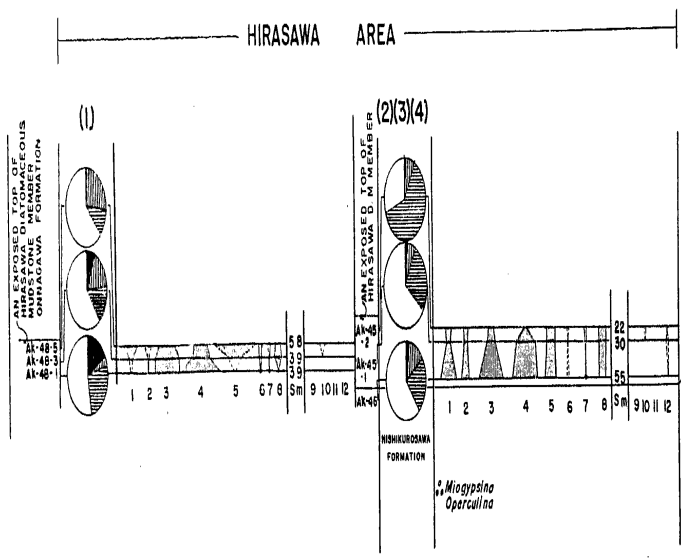
HIRASAWA AREA

*	Species	Ak-47 (C. Yabei assemblage)	Ak-49-1 (Assemblage A)	Ak-49-2 (Assemblage A)
1	*Coscinodiscus Yabei*			
2	*Stephanogonia Hanzawae*	4		1
3	*Actinocyclus tsugaruensis*	15	4	2
4	*Actinocyclus ingens*	1		
5	*Coscinodiscus Endoi*		1	1
6	*Stephanopyxis Schenckii*		1	2
7	*Coscinodiscus vetustissimus*	1	4	1
8	*Stephanopyxis cfr. ferox*	1		2
Sm	Total frequencies of marker species	22	10	9
9	*Endictya japonica*			
10	*Rouxia Peragalli*			1
11	*Cocconeis antiqua*			
12	*Cocconeis formosa*			
13	*Coscinodiscus marginatus*	22	19	18
14	*Fragilaria hirosakiensis*	26	94	90
15	*Denticula lauta*	10	23	25

* Abbreviations used in diagrams







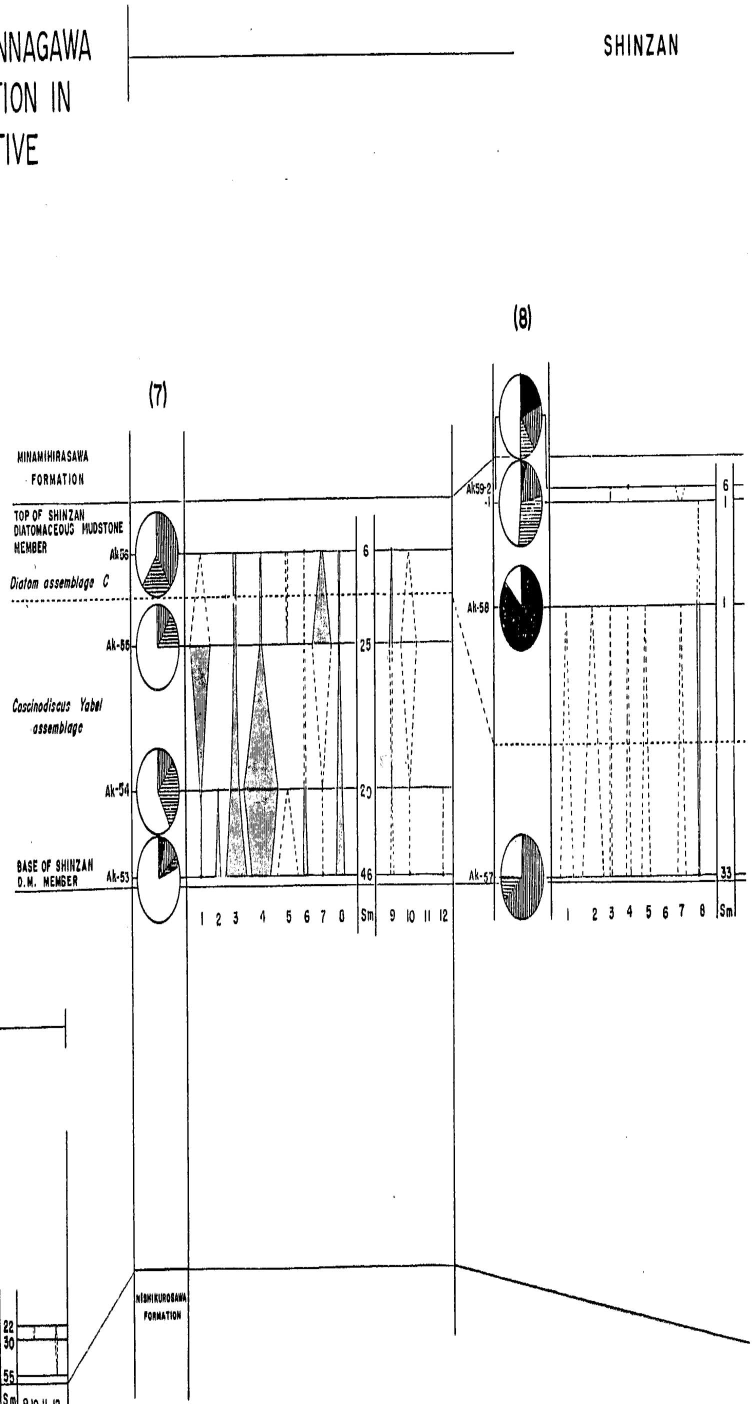
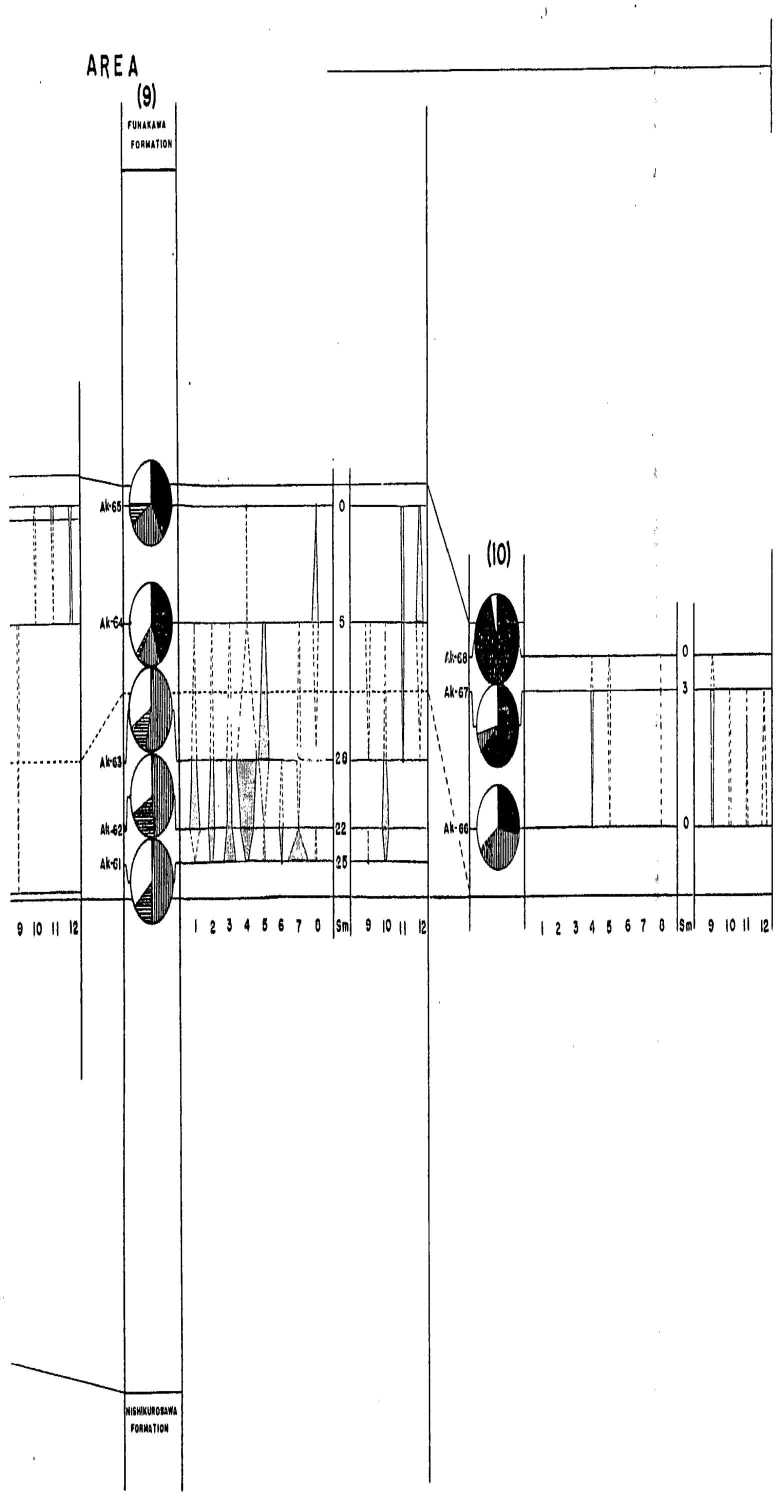


CHART 7

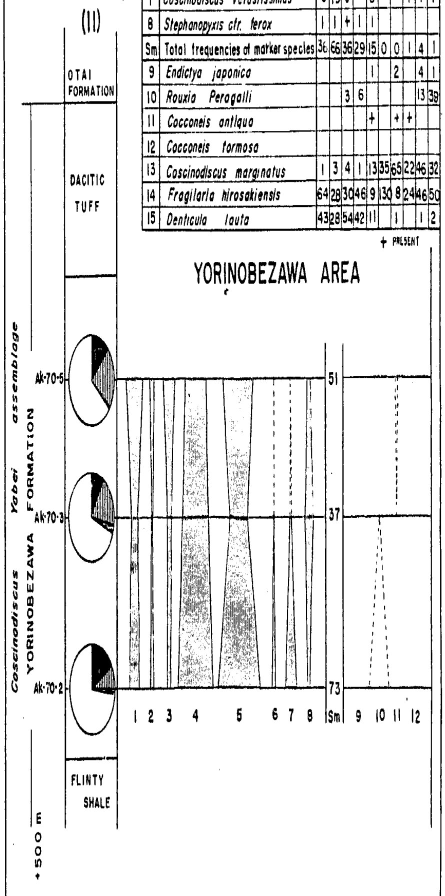


Assemblages in the Samples not illustrated

		HIROSAKI AREA OWASAWA FM: C. Yabei ASSEMBLAGE					OF HIGHER HORIZONS				
	Species	Ao-10	Ao-11	Ao-9	Ao-12	Ao-13	Ao-26	Ao-24	Ao-25	Ao-27	Ao-28
1	*Coscinodiscus Yabei*	1	1	3	5						
2	*Stephanogonia Hanzawae*		+	+	+			+			
3	*Actinocyclus tsugaruensis*		25	2	+	2				2	
4	*Actinocyclus ingens*	20	15	12	10	9	+	+		1	+
5	*Coscinodiscus Endoi*	5	5	16	12						
6	*Stephanopyxis Schenckii*		+		1	+					
7	*Coscinodiscus vetustissimus*	9	19	3		3			1	1	1
8	*Stephanopyxis cfr. ferox*	1	1	+	1	1					
Sm	Total frequencies of marker species	36	66	36	29	15	0	0	1	4	1
9	*Endictya japonica*					1		2		4	1
10	*Rouxia Peragalli*			3	6					13	39
11	*Cocconeis antiqua*					+		+	+		
12	*Cocconeis formosa*										
13	*Coscinodiscus marginatus*	1	3	4	1	13	35	65	22	46	32
14	*Fragilaria hirosakiensis*	64	28	30	46	9	130	8	24	46	50
15	*Denticula lauta*	43	28	54	42	11		1		1	2

+ PRESENT

YORINOBEZAWA AREA



Stephanopyxis Schencki Kanaya, n. sp.

Total frequencies of the eight marker species are apparently higher in the assemblage B, than those in the assemblage C (see "Sm" of Chart 7), and the difference is inferred to be statistically significant. Namely, the highest total frequencies of the eight marker species obtained from the samples in the assemblage C was X=6 (at IGPS loc. no. Ak-59-2, and Ak-56, see also Chart 6), whereas the lowest total frequencies of the marker species obtained from the assemblage B was X=22 (at IGPS loc. no. Ak-45-2, Ak-62 and Ak-47). The confidence intervals of the two values do not overlap at 95 percent confidence and the sample of size 200 (200 values), since the upper limit of expection for X=6 is 12.8, whereas the lower limit for X=22 is 14.0 (see Kanaya, 1957, Chart IV).

Although the total frequencies of the marker species is seemingly higher in the assemblage B than in A, the difference is not inferred to be statistically significant, inasmuch as the upper limit of expectation corresponding to the highest X=10 (at IGPS loc. no. Ak-49-2) is 18.0, thus overlaps in the confidence limits with that of X=22, the lowest value in the total observed frequencies of the marker species in the assemblage B. Therefore, other criteria should be added to distinguish the assemblages A and B, and assemblages A and C, and by doing so the three assemblages are distinguished as follows. *Diatom assemblage* A-The total frequencies of the eight marker species are low, and *Coscinodiscus Yabei* is lacking.[9] *Diatom assemblage* B-The total frequencies of the eight marker species is higher than X=14 in a random sample of 200 specimens at the confidence coefficient 95 percent: and *Conscinodiscus Yabei* is restricted to this assemblage. The assemblage is named *Coscinodiscus Yabei* assemblage, taking the species as an index of the assemblage. *Diatom assemblage* C-The total frequencies of the eight marker species is lower than X=13 in a random sample of 200 specimens. Both *Coscinodiscus Yabei* and *Stephanogonia Hanzawae* are lacking in the assemblage; *Cocconeis antiqua* and *Cocconeis formosa* appear, and a rather abrupt increase of *Coscinodiscus marginatus* usually coincide with the marked decrease of the total frequency of the eight marker species.[10]

The assemblages A and C, are not distinguishable by the total frequencies of the eight marker species, and both lack *Coscinodiscus Yabei*. The latter lacks

9) It might be added in this connection that, as was mentioned in Chapter II, species is judged to be absent in the present study, not only by the lacking of species in the counting of 200 specimens, but also by the examination of the entire field of two strewn slides prepared for a sample. Hence, the absence is not a mere zero frequency of the Poisson distribution (see Kanaya, 1957, p. 60), and should be closer to the Parameter X, true frequency in the sample, than the observed frequencies obtained by the counting, and therefore, is distinguished in the present study from X=1 obtained by counting.

10) On out of four Cases observed in the section of the Shinzan diatomaceous mudstone member (see Chart 7).

Stephanogonia hanzawae but the species is not necessarily present in the former. Discrimination of two assemblages is, however, rather easy, if one takes the abrupt increase of *Cosinodiscus marginatus* in the assemblage C on one hand, and the the absence of *Cocconeis antiqua*, and *Cocconeis formosa* in the assemblage A on the other. Furthermore, the appearance of *Thalassiosira Usatchevii*, which is often a common element of still younger assemblages, gives the assemblage C a younger appearance than assemblage A. Assemblages at IGPS loc. nos. Ak–48–1 and Ak-47 of the Hirasawa diatomaceous mudstone member, and Ak–61 of the Shinzan diatomaceous mudstone member, are tentatively included in the *Coscinodiscus Yabei* assemblage, despite that they lack *Coscinodiscus Yabei*, because the total frequency of the eight marker species indicate that they have the aspect of *Coscinodiscus Yabei* assemblage in composition.

Distribution of the assemblages in the Onnagawa formation

(see Chart 7, and also Charts 2, and 3)

Hirasawa area

(Chart 7, see also Chart 2)

Coscinodiscus Yabei assemblage is distributed in the Hirasawa diatomaceous mudstone member exposed in the area around Hirasawa village (Chart 2). A sample taken from a locality (IGPS loc. no. Ak–47), 1000 m south of Hirasawa village also contains the assemblage.

The diatom assemblage A is represented by two samples at a locality (IGPS loc. no. Ak–49) which, being 1600 m south from Hirasawa village, marks the southernmost extension of the Hirasawa diatomaceous mudstone member in the area. Stratigraphic position of this marginal locality with regard to the typical Hirasawa section (1, 2, 3, 4, in Chart 2) was not precisely known, because the key bed for tracing the typical section to this locality is lacking. Neverthless, it can be said that the two samples are within a thickness of 5 m above the top of the Nishikurasawa formation at the locality, and are a few meters higher than that from Ak–47 which yields the *Coscinodiscus Yabei* assemblage, as just mentioned.

It is not likely that the assemblage A was not found in the typical Hirasawa sections at Hirasawa village because the vertical sampling intervals were too long, inasmuch as the *Ccscinodiscus Yabei* assemblage there represented in the examined samples keeps the assemblage characteristic compositionally stable. It is more likely that the assemblage A is a local facies which was formed in a marginal part of the area where the *Coscinodiscus Yabei* assemblage was to be predominating.

Shinzan area

(Chart 7, see also Chart 3)

Coscinodiscus Yabei assemblage is distributed in the lower half of the Shinzan diatomaceous mudstone member. The thickness of the strata containing the assemblage differs in sections, but their thickness manifested on the chart (Chart 7) is by no means dependable, since the boundary between an upper assemblage, the assemblage C, is arbitarary drawn by taking the midpoint, at each section, between the studied highest and lowest occurrences of the two assemblages. Nevertheless, the chart shows that the strata containing the *Coscinodiscus Yabei* assemblage is thicker in the west, becomes thinner to east, and is lacking at the easternmost section (section 10) obtained in the area. The lower boundary of the assemblage containing strata is the lower boundary of the diatomaceous mudstone of the area, the Shinzan diatomaceous mudstone member.

Diatom assemblage C distributes in the upper part of the Shinzan diatomaceous mudstone member. Generally speaking, the strata containing this assemblage is thin in the west, and becomes thicker to the east, and in the easternmost section, the assemblage C distributes through the entire thickness of the Shinzan diatomaceous mudstone member. The assemblage is always stratigraphically higher than the *Coscinodiscus Yabei* assemblage, and is distinctly different from the latter, as was mentioned before.

The marked increases of *Coscinodiscus marginatus*, it seems, roughly coincide with the appearance of fine grained glauconite in the diatomaceous rocks which is partly responsible to make the upper part of the Shinzan diatomaceous mudstone member sandy, and with the rocks becoming sandy, the diatom contents decrease.

The upper boundary of the assemblage C bearing strata coincides with that of the Shinzan diatomaceous mudstone member.

Assemblages from the Yorinobezawa Formation

(Chart 7, see also Chart 4)

The Yorinobezawa formation (600 m thick) bears diatomaceous mudstone in its uppermost part in the Yorinobezawa area, about 2.5 km southeast of Yonaizawa-machi, Akita Prefecture. Three samples were collected[11] from the section where the mudstone attains 45 m thick (see Chart 4).

Floral aspect shown in the three samples studied is about the same as of the Onnagawa formation: there is no species which is lacking in the Onnagawa

11) Collected by Mr. T. Kotaka, in July, 1950.

samples and is peculiar to this assemblage. A few differences noticed may be worth mentioning. *Coscinodiscus marginatus* which is almost ubiquitous and sometimes becomes dominant in the Onnagawa samples is lacking here; an exceptionally high (60 in 200) frequency of a neritic *Actinoptychus senarius* (Ehr.) Ehr. was found in one sample (Ak–70–3); and *Asteromphalus moronensis* (Grev.) Ratt, which is less than rare when it occurs in the Onnagawa formation samples, appeared in one sample (Ak–70–5) frequently (13 in 200 specimens counted).

The same analysis as was applied to the samples of the Onnagawa formation, indicates that the assemblage represented by the three samples definitely has the defined characterstics of the *Coscinodiscus Yabei* assemblage the total frequencies of the eight marker species are sufficiently high enough to be qualified so; as an index species of the assemblage, *Coscinodscus Yabei* is present in all three samples.

Assemblages from the Owasawa Formation

(Chart 7, and Chart 5)

Five samples representing five localities were examined for the present study. They are samples from IGPS loc. no. Ao–10. Ao–11, Ao–9, Ao–12, and Ao–13. Exact stratigraphic positions of the first four samples were unfortunately not ascertained in a typical seuqence of the formation, due to the faults and dykes disturbing the structure. Nevertheless, it can be said that the four samples were from at least the lower 250 m of the Owasawa formation, which, in the area south of Hirosaki City, was measured to have 600 m in thickness.

The remaining one, from IGPS loc. no. Ao–13, was collected from a different section about 9 km east of the one from which the four samples were collected. Judging from the field evidence, the locality represents the uppermost portion of the Owasawa formation[12]).

Floral aspect shown in the lower four samples is the same as of the Onnagawa formation and the Yorinobezawa formation, whereas, the assemblage in the upper one sample shows a different aspect from that of the Onnagawa and Yorinobezawa assemblages. What is responsible for giving the assemblage the different floral aspect is the appearance of the following species which are lacking in the Onnagawa formation samples and those from the Yorinobezawa, as well as form the lower four samples of the Owasawa. They are:

Aulacodisucs amoneus Grev. var. *hungaricus* Pnt.

12) Mr. T. Iwai of Hirosaki University proposes the Matsukitai formation for this portion of the Owasawa formation in his study of the stratigraphy of the area now in progress.

Actinoptychus cfr. *splendens* var. *Halionyx* Grun, ex Van
as are shown on the distribution chart, and

Stictodiscus cfr. *argus* Schmidt (Reinhold, 1937, pl. 17, fig. 7–9)

Triceratium radiens forma *quadrata* Brun (Schmidt, 1881, pl. 166, fig. 6)
which are included under the miscellanea in the distribution chart. Although these four species occur very rarely in the samples, their previous records of occurrences suggest their importance from the paleobotanical point of view. *Aulacodiscus amoenus* var. *hungaricus* has so far been found only from its type locality, St. Peter deposit of Hungary, Helvetian in age (see the systematic description). Rare occurences of unnamed varieites of this species in the "Sendai" and "Yedo" materials were also mentioned by Brun and Tempère (1889, p. 69).

Actnoptychus splendens var. *Halionyx* and *Stictodiscus argus* were found to be restricted in Java to the Wanosari Series, "Middle Miocene" in age, though their upper range in the other parts of the wrold has not been precisely known (Reinhold, 1937).

Triceratium radiens forma *quadrata* was described by Brun from the "Sendai" material, and since then it has not been recorded from anywhere.

Besides the appearance of these four species, the assemblage at IGPS loc. no. Ao–13, is peculiar in having exceptional high frequency (51 in 200 specimens counted) of *Coscinodiscus elegans* Grev. *s. s.* as so applied in the present paper.

In terms of the criteria which defined the assemblages of the Onnagawa formation, the assemblages represented by the lower four samples of the Owasawa formation definitely shows the *Coscinodiscus Yabei* assemblage characteristic (Chart 7). The total frequency of the eight marker species is sufficiently high throughout the four samples (see Chart 7), and *Coscinodiscus Yabei* was found to be present in all of them.

The low freqeuncy (15 in 200 specimens counted) of the total of the eight species, (which is about at the lower limit as was given for the *Coscinodiscus Yabei* assemblage), and the lacking of *Coscinodiscus Yabei* indicate that the assemblage in the uppermost sample is different from the lower ones. This upper assemblage is different from the diatom assemblage C of the Onnagawa formation which in the Shinzan area succeeds the *Coscinodiscus Yabei* assemblage. *Thalassiosira Usatchevii* which first appears in the assemblage C in the Shinzan section, is lacking in this assemblage which comes in position likewise above the *Coscinodiscus Yabei* assemblage in this area. So faı as in terms of critiera defining the assemblages in the Onnagawa formation, the assemblage from the uppermost part of the Owasawa formation is more related to the *Coscinodiscus Yabei* assemblage, than to the assemblage C.

Assemblages of the Higher Horizons

(Chart 7)

The samples from the formations stratigraphically higher than the Onnagawa formation and its correlatives were examined with a purpose of eliminating long range species which might be incorporated otherwise to define the assemblages of the lower horizon. Therefore, the analysis of the assemblages of higher horizons themselves are only tentative and not satisfactory.

The samples here referred as of the higher horizons are one from the Iizume formation, two from the Maido formation, and two from the Matazawa formation. As was mentioned in Chapter I, these formations are of stratigraphically higher horizons than the Onnagawa and its correlatives, the Yoriinobezawa and Owasawa formations, and are considered to be of late Miocene in age. The Iizume formation is a correlative of the Funakawa formation, the Maido and Matazawa formations are correlatives of the Kitaura formation, and thus the former is of stage IV of Kitamura (1958), and the latter two are of stage V, where the Onnagawa and its correlative formation are of stage III, medial Miocene in age.

From the criteria by which the marker species of the Onnagawa assemblages were chosen, it is self evident that the total frequencies of the eight marker species are, as are shown in Chart 7, significantly low ; and that four out of the eight species, *Coscinodiscus Yabei*, *Coscinodiscus Endoi*, *Stephanopyxis Schenkii*, and *Stephanopyxis* cfr. *ferox* were barren in the five samples.

Comparing with the assemblage C in the Onnagawa formation, from which the five samples are not significantly different in the total frequency of the eight marker species, *Denticula lauta* is very rare in these samples of the higher horizons.

Several additional features peculiar to each of the five samples may be mentioned here. Generalization which positively characterize the assemblages of these two higher horizons can not be drawn at present, inasmuch as the knowledge so far obtained is only fragmental.

The sample (IGPS loc. no. Ao–26) from the Iizume formation is dominated by *Fragilaria hirosokiensis* (see distribution chart, Chart 6, and 7). The species is represented by the typical forms as was in the *Coscinodiscus Yabei* assemblage, but *Denticula lauta* is barren in this sample. The appearance of peculiar *Navicula*, which may be identified with *Navicula adonis* Brun (Brun and Temperé., 1889, pl. 5, fig. 3), and *Navicula reticulo-radiata* Temp. and Brun (Brun and Temp. *ibid.*, pl. 5, fig. 4) are noticealbe. *Thalassiosira Usatchevii* was not present in this sample.

The samples from the Maido formation (IGPS loc. no. Ao–24, Ao–25,) contain *Thalassiosira Usatchevii* consistently, which is rarer and sporadical in the assemblage C of the Onnagawa assemblages. Frequencies of *Stephanopyxis turris*

(Grev. et Arnott) Ralfs are significantly high (35 and 24 in 200 specimens counted for two samples), and such elements which are lacking in the Onnagawa samples as *Cocconeis scutellum*, large *Triceratium*, *Staurones* sp., *Diploneis* spp. gives the assemblage an entirely different aspect from those from the Onnagawa and its correlative formations.

The samples from the Matazawa formation (IGPS loc. no. Ao–27, Ao–28) are charaterized by high frequencies of *Rouxia* which are peculiar to the two samples examined. *Thalassiosira Usatchevii* which is consistent in the samples of the correlative Maido formation is lacking in the Matazawa samples.

The genus *Rouxia* is represented by two species in about equal proportion: namely *Rouxia Peragalli* Brun and Herib. which also occurs in the Onnagawa formation samples; and *Rouxia californica* M. Paragallo (Hanna, 1930a, pl. 14, fig. 6, 7), which is lacking the Onnagawa and its correlative formations so far ascertained from the present material.

Rouxia Peragalli has not been reported elsewhere than the type material, which are only known as to have been found from the Japanese localities, "Abokiri" and "limestone at Sendai" (see systematic description) whose geologic age and exact localities are unknown. *Rouxia californica* M. Peragallo on the other hand, has so far been found exclusively from California Miocene (Hanna, 1930a, p. 186).

> In his review of the genus *Rouxia*, Hanna wrote that *Rouxia californica* is widely distributed in California Miocene shales, but appear to be confined in its vertical range to this very narrow zone exposed in the Lompoc quarries and its stratigraphic equivalents elsewhere. (Hanna, *ibid.*, p. 187)

In this portion of the exposure at the Lompoc quarry the species is "excessively abundant", according to Hanna, and Hanna measured that the "*Rouxia* zone" is "about 500 feet down from the top diatomite as there exposed." The total thickness of the diatomite of the Lompoc quarry is about 1000 feet as measured by Bramlette (1946, p. 14). When this position is located on the columnar section given by Bramlette (1946, pl. 2, section 3), the "*Rouxia* zone" definitely falls in the Delmontian Stage of Kleinpell. Since the diatomite at the quarry is almost horizontal, and since its thickness has been well measured, the assignment seems to be certain. Another locality he mentioned, "nine miles west of Monterey in a position which may be 500 feet below the top of the shales in the type Monterey.", may fall also in the Delmontian Stage, with regard the Bramlette's section (1946, pl. 2, section 3). The Delmontian Stage of California has been customly called "Mio-Pliocene" by the students of Formainifera (Kleinpell, 1938, p. 181; Weaver et al, 1944), whereas, the students of metazoan fossil included it in Miocene (Wever, *ibid.*). Nevertheless, both schools seem to agree in placing the Delmontian and its correlative formations (except its uppermost part) as equivalent of the Sarmatian Stage of the European standard (Weaver, *ibid.*). The Sarmatian Stage is of Upper

Miocene by the subdivision of the Miocene Series suggested by Glaessner(1953, p. 657), to which the present writer follows.

Concluding Remarks

Taking previous records of occurrences, and frequencies of occurrences in the samples into consideration, 23 elements characterizing the diatom assemblages of the Onnagawa formation were first chosen. The observed frequencies were analysed further by consulting the distribution chart with their limits of expectations in mind, and it was found that if eight of the characterizing elements are selected as makers, comparison of the total frequencies of the marker species makes possible the reasonable grounding of the diatom assemblages of the Onnagawa formation with regard to the stratigraphic positions of the assemblages. Thus, using the total frequencies of the eight species as the main criteria, three diatom assemblages are recognized in the Onnagawa formation. They are:

Diatom assemblage A

Coscinodiscus Yabei assemblage

Diatom assemblage C

Among the three, *Coscinodiscus Yabei* assemblage is satisfactory defined by the high frequencies of the eight marker species, and by the presence of *Coscinodiscus Yabei* which is restricted to the assemblage.

The definition of the remaning two, however, are not satisfactory, inasmuch as they are distinguished from *Coscinodiscus Yabei* by the low frequencies of the eight marker species, rather than defined by positive elements characterizing the assemblages. Nevertheless, three assemblages are easily distinguishable from each other by objective critieria.

The distribution of each assemblages were traced into the stratigraphic sections of the Hirasawa and Shinzan areas of Oga Peninsula, and was found as follows. Diatom assemblage C always distributes in the strata stratigraphically higher than those containing *Coscinodiscus Yabei* assemblage, and the assemblage A is judged to be of a local marginal facies of the *Coscinodiscus Yabei* assemblage. The stratigraphically lowest distribution of the *Coscinodiscus Yabei* assemblage is that found near the base of the Hirasawa diatomaceous mudstone member in Hirasawa area where this member of the Onnagawa formation conformably overlies the Nishikurosawa formation which yields the *Miogypsina-Operculina* foraminifera fauna within a thickness of 15 m from its top. The stratigraphically upper boundary of the *Coscinodiscus Yabei* assemblage is found within the Hirasawa diatomaceous mudstone member of the Onnagawa formation from where the above diatom assmblages are occupied by assemblage C unitl it diminishes at the boundary with the overlying Minamihirasawa formation which is not diatomaceous.

The analyses with the same criteria were applied to the samples of the Yorinobezawa, and Owasawa formations which are distant correlatives of the Onnagawa formation of Oga Peninsula. As a result, the assemblages of these two formation were also successfully identified as of *Coscinodiscus Yabei* assemblage in terms of the frequencies of the marker species and by the presence of *Coscinodiscus Yabei*. One sample from the uppermost part of the Owasawa formation did not qualify to be of *Coscinodiscus Yabei* assemblage, in terms of the criteria. Its floral aspect was also found to be different.

The floral charactersitics of the Onnagawa and its equivalent formations are radically changed at the higher horizons: the eight marker species which defines the *Coscinodiscus Yabei* assemblage are practically lacking there; and many of other elements characterizing the diatom flora of the Onnagawa formation disappear. The definitions of floral characterisitics of these higher horizons are not intended at present and are reserved for future study.

The facts that *Coscinodiscus Yabei* assemblage distributes in a wide area, while attaining its assemblage characteristic unchanged, and that the assemblage is satisfactory defined by the high frequencies of the eight marker species, which are themselves paleobotanically peculiar to the Japanese Miocene diatom flora, warrant to establish a biostratigraphic unit on the basis of *Coscinodiscus Yabei* assemblage. The unit has a nature of an assemblage-zone as was termed by the American Commission on Stratigraphic Nomenclature (1957, p. 1880–1881), that is "a bed or group of beds characterized by an assemblages of organisms, one of which is chosen to give its name to the unit although it need not be confined to this unit or found in every part of it. (*ibid.*, p. 1881).

Thus the *Coscinodiscus Yabei* assemblage zone refers to strata containing the *Coscinodiscus Yabei* assemblages. *Coscinodiscus Yabei* is qualified to be called as an index species because the species is a characterstic fossil of the assemblage, and is restricted, so far known, to the unit (*ibid.*, p. 1881, foot note).

It is the conclusion of the present analysis that the *Conscinodiscus Yabei* assemblage zone thus defined is distributed in the distomaceous mudstone of the middle Miocene Onnagawa and its correlative formations in Akita and Aomori Prefectures, Northeast Japan. Whether the assemblage characteristics is evolutional or environmental, and to what extent the zone is dependable for stratigraphic correlation will be determined by future tracing of this zone into different formations of different areas.

CHAPTER IV

SYSTEMATIC DESCRIPTIONS OF SPECIES

Class Bacillariophyta

Order Centrales Schütt, 1896
[as Centricae; emend. Karsten, 1928]
Family Discaceae Schütt, 1896
[as Discoideae; emend. Karstne, 1928.]
Subfamily Coscinodiscoideae, Schütt, 1896.
[as Coscinodisceae; emend. Karsten, 1928]
Tribe Melosirae Schütt, 1896
[as Melosirinae; emend. Karsten, 1928]

Genus **Melosira** Agradh, 1824
Melosira granulata (Ehrenberg) Ralfs
Pl. 1, figs. 1, 2

Gaillonella granulata EHRENBERG, 1843, K. Akad. Wiss. Berlin, Abh., 1841, p. 127, many figures (inaccessible).
Melosira granulata RAEFS, 1861, in PRICHARD, History of the Infusoria, 4th ed., p. 820 (inaccessible). - HUSTEDT, 1927, Kieselalgen, Teil 1, p. 248, fig.104 (with a complete list of synonyms). -HUSTEDT, 1930, in PASCHER, Süsswassflora, Heft. 10, 2d ed., p. 87, fig. 44. -HUBER-PESTALOZZI, 1942, in THIENEMAN, Binnengewasser, Bd. 16, Teil 2, 2. Halfte, p. 380, figs. 151, 152.

Figured specimens: IGPS coll. cat. no. 76682 (pl. 1, figs. 1a, 1b), 15μ in diameter, from IGPS loc. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation ; IGPS coll. cat. no. 76683 (pl. 1, figs. 2, forma *curvata* (Grunow) Hustedt), 6μ in diameter, from IGPS loc. Ak–44–2, Hirasawa diatomaceous mudstone member, Onnagawa formation.
Size range of measured specimens: 10–15μ in diameter, (excluding forma *curvata*).
Previous records of occurrences: The living representative of this species has been known as "Euplankter; in eutrophen Seen und Flüssen, stark verbreitet, besonders in der Ebene, seltener in Gebirge (Anden z.B.). Maximum im Hochsommer in norddeutschlan Seen" (Huber-Pestalozzi, *l.c.*.).

Okuno's record of this species from the Miocene Kunnui group (Okuno, 1952, p. 5, pl. 5, fig. 1, occupying 90% of the assemblage) is its earliest geologic occurrence so far reported from the diatomite of fresh-water origin. The occurrences of this fresh-water species in Tertiary and Quaternary marine deposits has been widely known. The present writer, as well as Ichikawa (1950, p. 54), has met the rare occurrences of the species in many marine diatomaceous rocks of Japan, ranging from medial Miocene to Pleistocene in age. Rather unexpectedly, Lohman (*l. c.*) found the species, though occurring rarely, in his North Atlantic deep-sea cores; and Kolbe discussed in considerable length about the presence of this species frequent in some of his equatorial Atlantic deep-sea cores (Kolbe, 1956, pp. 181, 158–162). Both Lohman and Kolbe believed that these occurrences of the fresh-water species in the deep-sea cores are allochthonous.[1]

Occurrences in the present material[2] (Chart 6) : The made of occurrence in the present material makes this fresh-water species useless at the analysis in terms of the stratigraphic distribution.

Melosira sol (Ehrenberg) Kützing

Pl. 1, fig. 3

Gaillonella sol EHRENBERG, 1845, Akad. Wiss. Berlin, Ber., 1844 p. 202 (inaccessible).

Melosira sol (Ehrenberg) KÜTZING, 1849, Spec. Alg., p. 31 (inaccessible). - VAN HEURCK, 1881, Synop. diatom. Belgique, pl. 91, figs. 7–9. - SCHMIDT, 1892, Atlas der Diatomaceenkunde, pl. 179, fig. 21. - DE TONI, 1894, Sylloge alagrum, p. 1341. - HUSTEDT, 1927, Kieselalgen, Teil 1, p. 270, fig. 115.

Size range of measured specimens : 30–45μ in diameter.

Figured specimen : IGPS coll. cat. no. 76684 (pl. 1, fig. 3), 43μ in diameter from IGPS loc. no. Ao–12, Owasawa formation.

Remarks : The specimens found in the present materials have radial striae which Hustedt classified as of his Type 1. (*l. c.*), but he described no markings for the inner-layer of the type was disolved in valve views. In spite of this, the present identification was possible by the presence of good specimens showing the characteristic girdle view of this species in the same slides.

Previous records of occurrences : Hustedt stated (*l.c.*) that the species "Lebt vorwiegend in den Südlichen Meeren, soll aber nach Peragallo auch an der krüste der

1) Later Kolbe (1957b) added a possibility of autochthonous origin for a certain level of a core (552 cm below the top of core 234) where diatoms were represented exclusively by 17 fresh-water species, including *M. granulata*, except a single fragment of a marine form.

2) Frequencies of species at each sample given in this chapter are the observed frequency from a single count of 200 diatom valves at each smaple (see the distribution chart, Chart 6), and do not include the limit of expectation. They are graded as follows : rare 1–5; frequent 6–19; common 20–39; abundant 40–59; very abundant 60–99; dominant more than 100 valves at a random sample of 200 valves. The species is regarded as very rare in a sample when it did not appear in the counting but was found present while examining entire fields of two strewn slides prepared for the sample. If a species was not found in the two strewn slides, the species is described to be absent in the sample.

Normandie vorkommen". The species was found in a bottom sample off Alaska (Mann, 1907, p. 239), as well as in equatorial deep-sea cores off the African coast (Kolbe, 1957, p. 37). An occurrence reported by Ichikawa (1950, p. 54) from the Miocene Iizuka formation, Noto Peninsula, Ishikawa Prefecture, Japan was the oldest geologic record of the species so far ascertained.

Occurrences in the present material (Chart 6) : Found very rare to rare in some of the samples from the Onnagawa formation, as well as in those from the upper horizons.

Melosira sulcata (Ehrenberg) Kützing

Pl. 1, figs. 4–7

Gaillonella sulcata EHRENBERG, 1838, Die Infusionstheirchen als vollkommene Organismen, p. 170, pl. 21, fig. 5. Locality : "Polierschiefer von Oran in der Barbarel".

Melosira sulcata (Ehrenberg) KÜTZING, 1844, Bacill., p. 55, pl. 2, fig. 7 (inaccessible). - VAN HEURCK, 1881, Synop. diatom. Belgique, pl. 91, figs. 15, 16. - SCHMIDT, 1892, Atlas der Diatomaceenkunde, pl. 178, figs. 1–5, 7–9, 22–24. - HUSTEDT 1928, Kieselalgen, Teil 1, p. 276, figs. 118, 119. - LOHMAN, 1941, U.S. Geol. Survey, Prof. Papers 196-B, p. 64, pl. 12, fig. 1. -KANAYA, 1957, Sci. Report Tohoku Univ., Sendai, 2d ser. (geology), vol. 28, p. 76, pl. 3, figs. 1, 2.

Paralia sulcata (Ehrenberg) Cleve, DE TONI, 1894, p. 1349,- SCHMIDT, 1892, Atlas der Diatomaceenkunde, pl. 176, figs. 28, 32–39, 42–44, 46.

Size range of measured specimens : 10–35μ in diameter.

Figured specimens : IGPS coll. cat. no. 76685 (pl. 1, figs. 4a, 4b girdle vfew), 8μ in diameter, from IGPS loc. Ao–12, Owasawa formation; IGPS coll. cat. no. 76686 (pe, fig. 5), 16μ in diameter, IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76687 (pl. 1, fig. 6, girdle view), 16μ in diameter, from IGPS loc. no. Ak–70–3, Yorinobezawa formation; IGPS coll. cat. no. 76688 (pl. 1, fig. 7, with two valves), 33μ in diameter, from IGPS loc. no. Ak–68, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks : The illustrations in the above cited list of synonyms indicate that the species has been accepted allowing a wide range of variation. More critical examination is needed to decide to which of these figures (they came from fossil and living samples of various sources) the present specimens fit best.

Previous records of occurrences : The previous records indicate that the species appeared since late Eocene, and is still living (Kanaya, 1957, p. 77). The species is ubiquitous in Japanese marine Miocene diatomaceous rocks.

Jousé reported that *Melosira sulcata* is a qualitatively abundant species in the bottom sediments of the Sea of Okhotsk (Joursé, 1957, p. 177); according to Lohman, the species was found in nearly every sample of the Northern Atlantic deep-sea cores he examined (*l. c.*); and Kolbe's studies revealed that the species is widespread but never appearing in great numbers in the cores of the equatorial

Indian Ocean (Kolbe, 1957, p. 37), rather rare in the equatorial Atlantic cores (1956, p. 37), and only represented by rare occurrences of var. *biseriata* (1954, p. 40) the equatorial Pacific cores. His mentioning that the species was totally missing in his "mid-ocean area" of Indian Ocean (*l. c.*) is of interest, because, being tychopelagic, this cosmopolitan species is fundamentally littoral in the present seas, though they are sporadically found in plankton. (Hustedt, *l. c.*; Lohman, *l. c.*; and Cupp, 1943, p. 41).
Occurrences in the present material (see Chart 6): The species was almost ubiquitous in the samples examined. It became frequent in several samples, but the generalization which makes the species stratigraphically useful was not drawn from the observed frequencies.

Genus ***Endictya*** Ehrenberg, 1845

Endictya japonica Kanaya, n. sp.

Pl. 1, figs. 8–10

Description: Valve circular, 20–45μ in diameter, about 10μ in height; surface flat with raised margin. Areolear polygonal, 2–2.5 in 10μ near center, slightly descrease their size outwardly and form a complete meshwork, leaving no central area, nor interstitial meshes. Valve margin not well defined, but circled by a somewhat raised edge from where the areolated cell wall truns down to from valve mantle.
Holotype: IGPS coll. cat. no. 76671 (pl. 1, figs, 8a, 8b), 24μ in diameter, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation.
Paratypes: IGPS coll. cat. no. 76672 (pl. 1, figs. 9a, 9b), 25μ in diameter, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formttion; IGPS coll. cat. no. 76673 (pl. 1, figs. 10a, 10b), 24,2μ in diameter, from IGPS loc. no. Ao–13, Owasawa formation.
Remarks: In the early stage of the present investigation, this species was tentatively identified as a small form of *Coscinodiscus marginatus* Ehr., but with more numbers of specimens examined, it has become evident that the peculiar marginal structure is consistent on these small diatoms. The marginal structure was found to be that of *Endictya*, because, in valve view, the marginal part are focused vertically through several rows of areolae as Lohman has suggested (Lohman, 1941, p. 66). The raised nature of the valve margin (Mann, 1907, p. 236) was also confirmed. The writer failed to orient specimens to see their girdle views, and the heights of valves were estimated to be less than 10μ, by the measuring the depth of focus.

The structure so far examined from valve view also suggests that of *Stephanopyxis*, but more or less "gekerbtem Rand", very flat valves with raised edge, and lack of spines make this comparison improbable.

The new species resembles *Endictya robusta* (Greville) Hanna and Gran (1936, p. 144, pl. 16, figs. 2, 3) in a sense that both species have *Coscinodiscus marginatus*-like areolation, but the new species is much smaller, and has the raised edge.
Occurrences in the present material (Chart 6) : The species was found very rare to rare in some of the samples of the Onnagawa formation, as well as in ones from the higher horizons.

Genus ***Stephanopyxis*** Ehrenberg, 1845

Stephanopyxis cfr. ***ferox*** (Greville) Ralfs

Pl. 1, fisg 11–13

Creswellia ferox GREVILLE, 1895, Quart. Jour. Micr. Sci., vol. 7, p. 166, pl. 8, figs. 15–16 (inaccessible).
Stephanopyxisferox (Greville) RALFS, 1861, in PRICHARD, Infusoria, 4th ed. p. 826, pl. 5, fig. 75 (inaccessible).- GRUNOW, 1884, K. Akad. Wiss. Wien, Abhand., Naturw. Kl., Bd, 48, p. 89. -GROVE and STURT, 1887, Quekett Micr. Club, Jour., p. 70. - SCHMIDT, 1888, Atlas der Diatomaceenkunde, pl. 130, fig. 15.- DE TONI, 1894, Syrloge Algarum, p. 1140.

Size range of measured specimens : 35–50μ in diameter.
Figured specimens : ISPS coll. cat. no. 76702 (pl. 1, figs. 11a, 11b, girdle view), diameter 36.5μ, pervalver length of the frustule 16μ+23μ; IGPS coll. cat. no. 76703 (pl. 1, fig. 12, valve view with valve surface up), diameter 39μ, pervalver length of the valve c.a. 22μ (measured by the depth of focus) ; IGPS coll. cat. no. 76704 (pl. 1, figs. 13a, 13b, valve view with the base of the valve up), diameter 52.5μ, pervalver length of the valve, c.a. 26μ; all from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation.
Remraks : Since neither the original description, nor the subsequent reference with good illustrations of this species was accessible to the writer, the specimens are tentatively identified with *Stephanopyxis ferox* in a sense that the species is similar to *Sephanopyxis turris*, and is distinguishable from *St. turris* only by having short spines projecting from the corners of areolae. The widening at the base of the mantle is weak, and is not seen in valve view as a hyaline margin. Areolae are somewhat smaller along the base of valve mantle.

In the present sample, areolae of diatoms identified with this species are coarser, being 2.5–3 in 10μ than that of *Stephanopyxis turris*. Pervalver length (height) of valves relative to valve diameter varies not only in individuals, but also within a frustule (see pl. 1, figs. 11a, 11b).
Previous records of occurrences : De Toni's check list (*l. c.*) indicates that the species occurred from such Paleocene localities as "Simbirsk", "Ananino", and "Archangelsk" (for age see Pia in Hirmer, 1927, p. 46). Grove and Sturt's note on their specimens

from Oamaru, New Zealand (up. Eocene, see Kanaya, 1957, p. 53) fit well to the present specimens. No living record was ever given.
Occurrences in the present material (Chart 6) : The species was found with variable frequency in most of the samples from the Onnagawa and its correlative formations, while the samples from the higher horizons were barren of this species. Within three diatom assemblages of the Onnagawa formation, it occurred more often in the lower two, A and B, than in C. Statistical inference indicates that the species plays a role, with the other seven marker species, to make the assemblage B (*Coscinodiscus Yabei* assemblage) distinguisabe from the others (Chart 7).

Stephanopyxis cfr. ***nipponica*** Gran and Yendo

Pl. 2, fig. 1.

Stephanopyxis nipponica GRAN and YENDO, 1914, Videnskapsselsk. Schrift. 1, Math. - Naturv. Kl., 1913, Puget Sound Biol. St., Univ. Washington, Publ., vol. 7, p. 433, fig. 7.-KOKUBO, 1955, Plankton diatoms, p. 121, fig. 122a, b.
Stephanopyxis sp. AKATSUKA, 1914, Fishery Rep., vol. 8, p. 5, pl. 1, fig. 2.

Size range of the measured specimens : 25–35μ in diameter.
Figured specimens : IGPS coll. cat. no. 76705 (pl. 2, figs. 1a, 1b), diameter 25μ, pervalver length of a frustule 32μ, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation.
Remarks : The main characteristic of the species is its spines which, arising at the valve surface, reach directly the valve of the sister frustule. Such a nature, however, was not confirmed for the specimens examined, inasmuch as the frustules in a chain were not available. Accordingly, the present identification was made only by such secondary characters manifested on Akatsuka's figure (*l. c.*) as 1) the nearly spherical outline of a cell, 2) and the regularly arranged areolae on the valve mantle which become slightly larger toward the valve surface.
Previous records of occurrences : According to Akatsuka (*l. c.*) *Stephanopyxis nipponica* appeared among the plankton diatoms in Takashima area, west coast of Hokkaido, from October to May, and particularly often during a period from January to March. The surface temperature of the period was measured to have ranged from 2.0°–4.5°C. Jousé (1957, p. 177) found that the species is neritic and widespread in the bottom sediments of the sea of Okhotsk.
Occurrences in the present material (Chart 6) : Found very rare to rare in a few samples of the Onnagawa formation, and of the Yorinobezawa formation.

Stephanopyxis Schenckii Kanaya, n. sp.

Pl. 2, figs. 2–4.

Description : Valve circular, 35–70μ in diameter, arched as high as 1/3 to 1/2 of valve diameter, and with an acute brim at the base of valve mantle. Areolae coaıse, hexagonal, attaining nearly equal size (1.5–2 in 10μ) over the valve surface and mantle, except on the brim where they are larger and radially eleongated in petal-shape. Areolae arranged in the three systems of straight tangential sculptures; no radial arrangement develops. On entire valve, short spines present at the corners of areolae; no stronger spines visible. The brim at the base of valve mantle consists of slope extending from the mantle, and a flat hyaline margin, 2.4–4μ in width. The petal-shaped marginal areolae are on the slope; spinules are on the hyaline margin, corresponding in position to the boundary of each marginal areola; and minute puncta, 10 in 10μ, are on the edge of the hyaline margin.

Holotype: IGPS coll. cat. no. 76706 (pl. 2c, figs, 2a, 2b, valve view), 57μ in diameter, pervavler length (height) of the vavle c.a. 26μ (measured by depth of focus), areoleae 2 in 10μ, from diatom loc. 3, Owasawa formation.

Paratypes: IGPS coll. cat. no. 76707 (pl. 2, figs. 3a, 3b, valve view) diameter 62μ, pervalver length c.a. 20μ, areoleae 1.5 in 10μ; IGPS coll. cat. no. 76708 (pl 2, figs. 4a, 4b, half-tilted girdle veiw), diameter 39μ, both specimens are from the same locality as the holotype.

Remarks: With short spines placed at the corners of each areola, the new species stands close to *Stephanopyxis ferox* (Grev.) Ralfs, from which it differs in having the brim bearing petal-shaped areolae, and the hyaline margin. Valves are larger, and less arched, and areolae are coarser in the new species than in *St. ferox*.

In valve view, the new species bears the appearance of *Stephanopyxis Grunowii* Grove and Sturt (in SCHMIDT, 1888, pl. 130, figs. 1–4), for which Gove and Sturt gave no description. Schmidt who first illustrated the species did not describe the species On one of his figure (*l. c.*, pl. 130, fig. 1, showing the valve view), one would notice the short spines at the corners of areolae, but his other figures, including fig. 4 showing a girdle view, lack such spines. Hanna who found that *St. Grunowii* was the most common one in the upper Cretaceous Moreno shale (Hanna, 1927, p. 33, pl. 4, fig. 12) wrote that "The development of spines is very errastic, the specimen figured being without, but in others they are as large and variable in number and size as Schmidt has shown." The statement is not clear whether he distinguished two types of spines: the short spines at the corners of areolae, and longer and stronger spines forming a crown on valve mantle. The short spines are always present on the present specimens examined, while the longer spines do not appear to be present.

Under the circumstance, the present writer takes the liberty of proposing a new species for the Japanese specimens, and leaves for future study the critical examinations of the late Cretaceous Moreno shale and the late Eocene Oamaru materials, as well as Miocene samples of California and Java, from where *Stephanopyxis*

Grunowii were also reported (Hanna, *op. cit.*, p. 34; Reinhold, 1937, p. 114, pl. 15, figs. 12a, b).

Occurrences in the present material (Chart 6) : The species was found fairly consistent, with low frequencies, in the samples of the assemblage A and B (*Coscinodiscus Yabei* assemblage) of the Onnagawa formation, as well as in the samples of the Yorinobezawa and Owasawa formations, whereas, samples of the upper horizons were barren of this species.

The species is chosen as one of the marker species, whose joint occurrences define the assemblage B (*Coscinodiscus Yabei* assemblage) in the Onnagawa formation (Chart 7).

Stephanopyxis turris (Greville et Arnott) Ralfs

Pl. 2, figs. 5–7.

Creswellia turris Greville et Arnott, in Gregory, 1857, Roy. Soc. Edinburgh, Trans., vol. 21, pt. 4, p. 64, pl. 6, fig. 109 (inaccessible).

Stephanopyxis trurris (Greville et Arnott) Ralfs, 1861, in Pritchard, Infusoria, 4th ed. p. 825, pl. 5, fig. 74-Grunow, 1884, K. Akad, Wiss. Wien, Denkschr. Math. -Naturw. Kl., Bd. 48 p. 87. -Schmidt, 1888, Atlas der Diatomaceenkunde, pl. 130, figs. 42, 43. -De Toni, 1894, Sylloge Algarum. p. 1138. -Hustedt, 1928, Kieselalgen, Teil 1, p. 304, fig. 140. -Cupp, 1943, Scripps Inst. Ocean., Univ. California, Bull., vol. 5; no. 1, p. 40, fig. 9. -Kanaya, 1957, Sci. Rep. Tohoku Univ., Sendai, 2d ser. (Geology), vol. 28, p. 80.

Size range of measured specimens : 15–50μ in diameter.

Figured specimens : IGPS coll. cat. no. 76709 (pl. 2, fig. 5), diameter 15.4μ, pervalver length of a frustule 44μ, IGPS coll. cat. no. 76710 (pl. 2, figs. 6a, 6b), diameter 22μ, pervalver length of frustule 75μ, both from IGPS loc. no. Ao–13, Owasawa fortion; IGPS coll. Cat. no. 76711 (pl. 2,figs. 7a, 7b), diameter 45.6μ length of a valve 45.6μ, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudustone member, Onnagawa formation.

Remarks : While the size of areolae remains fairly constant, 3.5–4 in 10μ, the valve diameter and pervalver length (height) vary widely. In some specimes examined, the pervalver length relative to the valve diameter gets so long that it gives the specimens the appearance of var. *cylindrus* Grunow, the variety is distinguished from the species by its longer pervalver length and fewer spines (Grunow, *l.c.*; Hustedt, *l.c.*). It was not intended, however, in the presetn study, to distinguish var. *cylindrus* from *Stephanopyxis turris*, since the spines once existed on a valve when alive do not necessarily become preserved in the fossil specimen.

Stephanopyxis turris; the writer examined the girdle view in the samples studied, it always had two valves of a furstule in equal heights.

Previous records of occurrences : Previous records indicate that the species has a long geological history ranging from late Eocene to Recent (Kanaya, *l. c,*).

As for the living representative of this species, Hustedt stated (*l. c.*) that the species is not rare in the European seas, accounted for Gran's remarks (1905, p. 14) which mentioned that the northern limit of the distribution of this speices is Romsdal, Norway (63° Lat. N.). Hustedt, however, beared a doubt about its southern origin suggested by Gran.

No *Stephanopyxis* was reported by Lohman (1941) in his extensive studies of the deep-sea cores of the North Atlantic, between Newfoundland and Greenland.

Recently Kolbe made an interesting comment (1957, p. 42) after making thorough studies on diatoms in deep-sea cores raised from the equatorial belt of the Pacific, Atlantic, and Indian Oceans. According to Kolbe, the genus *Stephanopyxis* was altogether lacking in the sediments of the equatorial Pacific and Atlantic Oceans, while it was met with in the bottom cores of the equatorial Indian Ocean, where, with one exception [core 119], four species of *Stephanopyxis* found were confined to the western part of the area; district WI [West Indian Ocean], and A [African Coast]. *Stephanopyxis turris* was one of the four species, and was "observed in fair numbers in the Eastern [core 119] and Western parts of the area. It was markedly frequent in cores 156 and 157 [of African coast], and usually represented by its "*cylindrus*" (Kolbe, *l.c.*).

Occurrences in the present material (Chart 6): The exceptionally high frequencies of two samples of the Maido formation suggest that the species may become useful for stratigraphic analysis when more knowledge concerning the diatom assemblages of the horizons higher than the Onnagawa and its correlative will be accumulated.

Stephanopyxis ? limbata Ehrenberg
cfr. var. ***Crista-galli*** Tempère and Brun
Pl. 3, fig. 1.

Stephanopyxis limbata Ehrenberg var. *Crista-Galli* Tempère et Brun, Brun and Tempère, 1889, Soc. Phys. d'Hist. Natur., Genève, Mém., Tome 30, no. 9, p. 57, pl. 8, figs. 8a, b.

Locality: "Calcaire de Sendai et de Yédo".

Figured specimen: IGPS coll. cat. no. 76712 (pl. 3, figs. 1a, 1b), apical length 74μ, transapical length 42μ, from IGPS loc. no. Ak-48-5, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: This peculiar diatom is apparently allied to *Stephanopyxis* ? *limbata* Ehrenberg, described from the "Richmond" materials. Its spines, however, are not "dreikantig" as known for *St.* ? *limbata* (Grunow, 1884, p. 92; De Toni, 1894, p. 1144); on the other hand the reticular structure described by Brun and Tempère (*l. c.*) for their variety *Crista-galli* was not observed on the present specimen.

Since Ehreberg's original figure for the species was not accessible to the present writer, the comparison was made with Van Heurck's figure of *St.* ? *limbata* (Van Heurck, 1881, pl. 83, ter., fig. 13–14, from "S. Monica"), and var. *Crista-galli* (*l. c.*). Except that the reticulate markings are invisible, the present specimen is almost identical with the original figure of var. *Crista-galli* in valve view, while it is different from Van Heurck's figure in margin which in the Van Heurck's figure becomes narrower at the apical portions. Hence, the writer tentatively identifies the present form with var. *Crista-galli*.

As Grunow has suggested (1884, p. 92), *Stephanopyxis* ? *limbata*, and thus its variety, should be excluded from the genus *Stephanopyxis* to form a separate genus, but such a practice is better be reserved until sufficient numbers of adequate specimens will become available.

Previous records of occurrences: Found so far only from the type material (*l.c.*), exact locality and geologic age of which remains unknown. *Stephanopyxis* ? *limabta* Ehr. has been reported only from "Richmond", Virginia, and "S. Monica", California (De Toni, 1894. p, 1144). The former is of the Calvert formation, medial Miocene in age (Kanaya, 1957, p. 55), and the latter is probably also of Miocene in age.

Occurrences in the present material (see Chart 6): Finding of this form in two samples of the Onnagawa formation is interesting, since the species has so far been reported only from the type material.

Tribe Sceletonemieae Schütt

[as Sceletoneminae; emend. Karsten]

Genus ***Thalassiosira*** Cleve, 1873

Thalassiosira decipiens (Grunow) Jørgensen

Pl. 3, figs. 2, 3.

Coscinodiscus excentricus var. ? *decipiens* GRUNOW, 1878, in SCHNEIDER, Naturw. Beitr. Kennt. Kaukasualander, p. 125, pl. 4, fig. 18 (inaccessible).

Coscinodiscus decipiens GRUNONW ex VAN HEURCK, 1881, Synopsis diat. Belgique, pl. 91, fig. 10.

Thalassiosira decipiens (Grunow) JΦRGENSEN, 1905, Hydrogr. biol. invest. Norw. fiords, p. 96, pl. 6, fig. 3 (inaccessible). - HUSTEDT, 1928, Kieselalgen, Teil 1, p. 322, fig. 158 -LOHMAN, 1941, U.S. Geol. Survey, Prof. paper 196-B, p. 67, pl. 12, fig. 8. -CUPP, 1943, Scripps Inst. Oceanography, Univ. California, Bull., vol. 5, no. 1, p. 48, fig. 10.

Coscinodisucs (*Thalassiosira*) *decipiens* (Grunow) Cleve, CLEVE-EULER, 1952, Kungl. Svenska Vetenskapakad., Handl. 4th ser., vol. 2, no. 1, p. 71, fig. 116a-c.

Size range of measured specimens: 20–35μ in diameter.

Figured specimens: IGPS coll. cat. no. 76713 (pl. 3, fig. 2), 23μ in diameter, from IGPS loc. No. Ak–59, Shinzan diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76714 (pl. 3, fig. 3, showing marginal structure),

22.8μ in diameter, from IGPS loc. no. Ak–67. Shinzan diatomaceous mudstone member, Onnagawa formation.
Remarks: To distinguish *Thalassiosira* from *Coscinodiscus* in fossil specimens is not an easy task, since the gelatinous threads of *Thalassiosira* uniting frustules in chain when alive are not preserved in the fossil status.

The present identification was, therefore, made on the basis of similarity of surface areolation wirth Van Heurck's figure (*l.c.*), and the species was distinguished from *Coscinodiscus excentricus* Ehr. in having finer areolation, 9–10 in 10μ near the center; by the presence of a small eccentric nodule in valve center of some of the specimens; by marginal spinules being rather strong on some of the specimens (pl. 3, fig. 3); and by smaller valve sizes than that of *Coscinodiscus excentricucs* in the same samples.
Previous records of occurrences: According to Lohman (*l.c.*) the oldest known geologic occurrence of this species is late Eocene. The records in younger Tertiary formations have so far been lacking : this is probably due to that the species has been confused wirth *Coscinodiscus excentricus* Ehr..

Kolbe stated (1957, p. 44) that

> *Thalssiosira decipiens* has obviously a world wide distribution. Common in the northern hemisphere, it is very widespread in the sediments of the Equatorial Pacific and Atlantic Oceans. Hendy records its from the Peru Current and off the Chilean Coast. In the core from the equatorial Indian Ocean it was not only widespread but fairly frequent at all levels of the cores.

Jousé (1957, p. 178) found *Thalassiosira decipiens* Jørg., and *Th. excntrica* Cleve in the bottom samples of the Sea of Okhotsk, and remaked that the latter species is qualitatively abundant in the area. Judging from her figure (pl. 4, figs. 1–3), the writer is of the impression that at least part of the diatoms Jousé identified with *Th. excentrica* Cleve (which is a synonym of *Coscinodiscus excentricus* Ehr.) could be *Th. decipiens* in the present paper.

As for the occurrences off Takashima, west of Hokkaido, Akatsuka (1914) found that the species was confined to surface catches through February to March; the surface temperature during the period ranged from 0°C to 4°5C. According to Aikawa (1936, from Kokubo, 1955) this is a common species of the cold Oyashio current.
Occurrences in the present material (Chart 6) : In the samples of the Onnagawa formation, the species was met more often in the samples containing the assemblage C, than those of the lower two, the assemblages A, and B. It is the writer's impression, what the species may be useful to define a Miocene assemblage, younger than the assembage B in the Onnagawa formation, together with other species including *Thalassiosira Usatschevii*, which as was mentioned, appears in the samples containing the assemblage C in the Onnagawa formation.

Tribe Coscinodisceae Schütt, 1896

[as Coscinodsicinae; emend. Karsten, 1928]

Genus ***Coscinodiscus*** Ehrenberg, 1838

Coscinodiscus argus Ehrenberg

Pl. 3, fig. 4.

Coscinodiscus Argus EHRENBERG, 1840, K. Akad. Wiss. Berlin, Phys. Abh., 1838, p. 129 (inaccessible). -GRUNOW, 1884, K. Akad. Wiss. Wien, Denkschr. Math. -Naturw. Kl., Bd. 48, p. 72, - SCHMIDT, 1888, Atlas der Diatomaceenkunde, pl. 113, fig. 7. - RATTRAY, 1889, Roy. Soc. Edinburgh, Proc., vol. 16, p. 527, - DE TONI, 1894, Sylloge algarum, p. 1253. - HUSTEDT, 1928, Kieselalgen, Teil 1, p. 422, fig. 226. - LOHMAN, 1941, U.S. Geol. Survey, Prof. Papers 196-B, p. 70, pl. 13, figs. 1,3. - KANAYA, 1957, Sci. Rep. Tohoku Univ., Sendai, Japan, 2d ser. (Geology), vol. 28, p. 84, pl. 4, figs. 1a, 1b, 2a, 2b, 3.

Coscinodiscus radiatus Ehrenberg, EHRENBERG, 1854. Mikrogeologie, pl. 21, fig. 1 (this figure only).

Coscinodiscus crassus BAILEY, 1856, Am. Jour. Sci., vol. 22, 2d. ser. p. 4.

Coscinodiscus heteroporus Ehrenberg var., SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 61, figs. 1, 4.

Coscinodiscus Woodwardii Eulenstein, SCHMIDT, 1878, ibid, pl. 61, fig. 2.

Coscinodiscus heteroporus Ehrenberg, SCHMIDT, 1878, *ibid.*, pl. 61, fig. 6.

Coscinodiscus crassus Bailey var., SCHMIDT, 1878, *ibid.*, pl. 61, fig. 19.

Size range of measured specimens: 80–160μ in diameter.

Figured specimen : IGPS coll. cat. no. 76632 (pl. 3, fig. 4), diameter 98μ, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks : *Coscinodiscus argus* Ehr. is distinguished from the similar species as follows : from *C. radiatus* Ehr. by its areolae increasing the size outwardly, and dieffrs from *C. obscurus* Schmidt in lack of the interstitial meshes which are well developed on the latter species at just before the ends of the secondary radial rows.

Various appearances of the central area of this species, once mentioned by Kanaya (*op. cit.*, p. 85) for his Eocene California specimens, are also found in the present specimens of the Japanese Miocene. Namely, there are individuals with an open central area, which grades into a group with almost completely areolated center, through another group of transitional forms. The variation corresponds to that shown in Schmidt's figure of *C. crassus* Bailey var. (Schmidt, 1878, *l.c.*, from Barbados), to *C. Argus* Ehr. (Schmidt, 1888, *l. c.*, from Aegina), though *C. heteroporus* Ehr. (Schmidt, 1878, *l. c.*, from Barbados), respectively.

Previous records of occurrences : Kanaya (1957, p. 85) cited the previous occurrences of this species and synonyms from geologically ascertained horizons, and found that the species ranges from the upper Eocene to Recent. Lohman believed that the heyday of this species has been reached and passed during previous geologic ages, although the species is still distributed in living as a "distinct warm water marine species" in the neritic region (Lohman, 1941, *op. cit.*).

Kolbe who found that this species is rare in the Pacific (1954, p. 28), more or less frequent in Atlantic (1956, p. 168), and rare in the Indian Ocean (1957, p. 29) equatorial deep-sea cores, went on to state that rare occurrence in the region of the Galapagos-Islands is perhaps "a confirmation of Hustedt's assumption that it is a littoral species" (Kolbe, 1954, p. 28; Hustedt, 1928, *l. c.*).

Occurrences in the present material (Chart 6): The species was found, in various frequency, in most of the samples examined.

Coscinodiscus curvatulus Grunow var. ***odontodiscus*** (Grunow) Hustedt

Pl. 3, fig. 5.

Coscinodiscus subtilis var., SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 57, figs. 15, 16 (these figures only).

Coscinodiscus odontodiscus GRUNOW, 1884, K. Akad. Wiss. Wien, Denkschr., Math. -Naturw. Kl., Bd. 48, p. 81, pl. 3, fig. 23. Locaty: Richmond, Virginia. - RAT-1889, Roy. Soc. Edinburgh, Proc., vol. 16, p. 485.

Coscinodiscus cruvatulus Grunow var. *odontodiscus* (Grunow) HUSTEDT, 1928, Kieselalgen, Teil 1, p. 408, fig. 215.

Size range of measured specimens: 50–80μ in diameter.

Figured specimen: IGPS coll. cat. no. 76633 (pl. 3, fig. 5), 55μ in diameter, from IGPS loc. no. Ak–67, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks: On the specimens examined, areoleae are fairly equal in size, being 5–6 in 10μ. The hyaline ring at the center is obvious, enclosing smaller porodis. By the presence of the hyaline ring, and by coarse areolae, the present specimens were distinguished from *Coscinodiscus bicurvatulus* Lohman (1941, p. 73, pl. 15, fig. 5). Sedondary spiral sculptures of areolae are consipcuous on inner half of radius as was shown on Schmidt's figure (Schmidt, *op, cit.*, pl. 57, fig. 16.)

Previous records of occurrences: Grunow's type figure (*l. c.*), and Schmidt's two figures (*l. c.*) come from "Richmond", Virginaia, which is according to Lohman (1948, p. 152), a Virginia locality of the Calvert formation, medial Miocene in age (Kanaya, 1957, p. 55). Several other occurrences of this variety, both fossil and living ?, were cited by Rattray (*l. c.*).

For the occurrence of this variety in the equatorial Pacific deep-sea cores Kolbe remarked that".... only a few specimens strictly conform to the diagnosis; otherwise only intermediate forms passing into the typical species." (1954, p. 28). According to him "*C. curvatulus* frequently occurs in Core 76 only, beginning at a certain depth of 521 cm and replacing *C. nodulifer*, which was dominant to this depth." (*ibid.* p. 128). The variety *odoutodiscus* was recorded to occur in Core 76, upper levels.

Occurrences in the present material (see Chart 6): The species was found very rare to rare in many samples from the Onnagawa and its correlative formations, as well as from the formations of the higher horizons.

Coscinodiscus elegans Greville

Pl. 3, figs. 6, 7

Coscinodiscus elegans GREVILLE, 1866, Micr. Soc. London, Trans., n. ser., vol. 14, p. 3, pl. 1, fig. 6. Locality: "Monterey deposits". -SCHMIDT, Atlas der Diatomaceenkunde, 1886, pl. 58, fig. 7; 1891, pl. 163, fig. 10. - PANTOCSEK, 1886, Foss. Bacill. Ungarns, Teil 1, pl. 16, fig. 141; pl. 24, fig. 216, - RATTRAY, 1889, Roy. Soc. Edinburgh, Proc., Vol. 16, p. 583, - OKUNO, 1952, Atlas fossil diatoms, pl. 7, fig. 7 (not fig. 6).

Size range of measured specimens: 15–25μ in diameter.

Figured specimesn: IGPS coll. cat. no. 76634 (pl. 3, fig. 6), 17.0μ in diameter, IGPS coll. cat. no. 76635 (pl. 3, fig. 7), 19.8μ in diameter, from IGPS loc. Ao–9, Owasawa formation.

Remarks: Greville's original description read "Disc small, with a smooth irregular umbilicus; granules rather large, equal, in radiating, not very close linees, which terminate in a narrow belt of minute crowded puncta; border stong, finely striate. Diameter about 0.03 mm." (Greville, *l. c.*). He further remarked that "The narrow punctate belt is scarcely so broad as the border. Granules large, circular, conspicuous, about 8 in 0.01 mm." (*l.c.*).

While examining Japanese fossil material, the present writer frequently met diatoms which looked to have all the appearance of Greville's description and figure, except the areolae are coarser, being 4–6 in 10μ. On closer examination, however, it was found that most of these specimens have a pseudonodule, though it is not always obvious. Since diatoms with a pseudonodule can not be of *Coscinodiscus*, the writer identified the specimens of *Coscinodiscus elegans* appearance with *Actinocyclus ingens* when a psudonodule is found present on them (see pl. 8, figs. 1–4). This leaves in *Coscinodiscus elegans* only specimens of smaller diameter less than 25μ. The diatoms referred in the present paper to *Coscinodiscus elegans* are smaller than Greville's original description, and look somewhat different, but still bear the characteristics of *Coscinodiscus elegans*.

As it was cited before, Greville mentioned nothing on the pseudonodule in his original description. However, there is a reason to doubt that he might have failed then to observe the structure, since the writer confirmed the presence of the pseudonodule on *Coscinodiscus elegans*-like specimens in samples from the type locality of the Monterey formation, California, (for locality, see Kanaya, 1957, p. 53) which at least is approximately of the same horizon as Greville's original materials.

Coscinodiscus elegans as accepted by previous Japanese workers may have included *Actinocyculs ingens* of the present paper. For instance, of two figures given by Okuno (1952, pl. 7, figs. 6, 7) for *Coscinodiscus elegans*, one (pl. 7, fig. 6) is of *Actinocyclus ingens*, showing clearly the pseudonodule at the left above of the figure.

Previous records of occurrences: The type locality, "Monterey deposits" (Greville, *l.c.*), presumably of the Miocene in age, exact locality in California unkown; San Joaquin formation, Kettleman Hills, Pliocene (Lohman, 1938, p. 82); Dolje and Elsd, Hungary (Pantocsek, *l.c.*), Elsd is of "Pontian stage, lower Pliocene", and Dolje is of the Sarmatian, according to Pia (1927, p. 46). In view of the confusing taxonomical status of the species, previous records of occurrences from Japanese Tertiary deposits are reserved

Occurrences in the present material (Chart 6): The species was found very rare to rare in most of the samples of the present material, except at sample Ao–13 from the uppermost portion of the Owasawa formation, where it occurred abundantly.

Coscinodiscus Endoi Kanaya, n. sp.

Pl. 3, figs. 8–11.

Description: Valve circular, flat, and with a hyaline submarginal zone and a narrow margin. Areolae round to sub-angular, fascicularly arranged, dividing the valve surface into 8–20 sectors; the areolae running parallel to the lateral longest row of each sector. Areolae equisize on smaller specimens, 8 in 10μ; little coarser in near center of larger specimens, 6.5–7 in 10μ. Interfascicular area present in front of the inner ends of shorter rows. Central area hyaline, small, irregular shaped, slightly inclined from the valve center, and with a distinct nodule (Papilli of Hustedt) placed at its edge. The area bears one or a few isolated poroids. The submarginal hyaline zone distinct, bounded in an irregular line with the outer ends of the rows of areolae. Margin clearly settled, and consists of a line of minute (10 in 10μ) poroids inside, and a hyaline layer outside. Marginal processes conspicuous, placed on the ring of minute poroids, at an extension of the longest row of each sector. With the valve becoming smaller, the number of sectors decreases, and the hyaline submarginal zone becomes wider relative to the valve diameter.

Holotype: IGPS coll. cat. no. 76636 (pl. 3, fig. 8) diameter 45μ, from IGPS

loc. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation.
Paratypes : IGPS coll. cat. cat. no. 76637 (pl. 3, fig. 9) diameter 61.5μ, from IGPS loc. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation : IGPS coll. cat. no. 76638, (pl. 3, figs. 10a, 10b), diameter 30μ, from IGPS loc. Ao–9, Owasawa formation; IGPS coll. cat. no. 76639 (pl. 3, figs. 11a, 11b), diameter 20.5μ, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa fromation.
Remarks : The new species shows a resemblance to *Coscinodiscus tabularis* Grunow ex Rattray and its variety *egregius* (Rattray) Hustedt, (Hustedt, 1928, p. 427, figs. 230a, b; Schmidt, 1878, pl. 57, fig. 43) from which it differs in having a distinct nodule in center, and by fascicular arrangement of areolae. From another related form, *Coscinodiscus vetustissimus* Pantocsek (Hustedt, 1928, p. 412, fig. 220) the new species is distinguished by its characteristic hyaline submarginal zone. the new species is distinguished by its characteristic hyaline submarginal zone.

The new species is named for Dr. Seido Endo, former Professor in Paleontology, Tohoku University, who first initiated the writer into the study of diatoms.
Occurrences in the present material (Chart 6) : Generally speaking, the species occurred more often in samples containing the diatom assemblage B of the Onnagawa formation. The joint occurrences of this species with the other seven marker species define the diatom assemblage B (*Coscinodiscus Yabei* assemblage) of the Onnagawa formation (Chart 7).

The species was found frequent to common throughout the Yoinobezawa samples, and was rare to frequent in all Owasawa samples but one from the uppermost portion of the Owasawa formation, where it was absent.

Coscinodiscus excentricus Ehrenberg

Pl. 3, figs. 12, 13.

Coscinodiscus excentricus EHRENBERG, 1841, Ber. Akad., Abh., 1939, p. 146 (inaccessible). SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 58, figs. 46–49. - VAN HEURCK, 1881, Syn. diatom. Belgique, pl. 130, figs. 4, 7, 8. - RATTRAY, 1889, Roy. Soc. Edinburgh, Proc. p. 461, - DE TONI, 1894, Sylloge algarum, p. 1210. HUSTEDT, 1928, Kieselalgen, Teil 1, p. 388, fig. 201. – LOHMAN, 1941, U.S. Geol. Survey Prof. Papers 196-B, p. 67, pl. 12, fig. 7; pl. 13, fig. 8.

Coscinodiscus labyrinthus ROPER, 1858, Quart. Jour. Micr. Sci., vol. 6, p. 21, pl. 3, figs. 2a-b (inaccessible).

Coscinodiscus minor Ehrenberg, SCHMIDT, 1888, Atlas der Diatomaceenkunde, pl. 113, fig. 9 (not elsewhere).

Coscinodiscus (*Thalassiosira*) *excentricus* (Ehrebnerg) Cleve, CLEVE-EULER, 1952, Kungl. Svenska, Vetenskapsakad., Handl. 4th ser. vol. 2, no. 1, p. 71, fig. 118a.

Size range of measured specimens : 35–60μ in diameter.
Figured specimens : IGPS coll. cat. no. 76640 (pl. 3, figs. 12a, 12b), 39μ in diameter;

IGPS coll. cat. no. 76641 (pl. 3, figs. 13a, 13b), 4.5μ in diameter, both from IGPS loc. no. Ak–59, Shinzan diatomaceous mudstone member, Onnagawa formation.
Remarks: Two types of tangential sculptures of areolae are known for the species, namely: straight sculptures, and ones concave outwards. The valve with the straight tangential sculptures resembles *Coscinodiscus lineatus* Ehr., from which it differs in areolae which gradually descrease their size outwardly. On the specimens examined, the areolae are 4.5–5 in 10μ near the center, 6–7 in 10μ in the submarginal border, wheras, areolae are fairly equal in the size on the valves of *Coscinodiscus lineatus* Ehr. Since the marginal spinules are not always conspicuous, it is logically probable that the valves of *Planktoniella sol* (Wallich) Schutt may have also been identified in the present study with *Coscinodiscus excentricus*.
Previous reccrds of occurrences: According to Lohman (1941, *l.c.*), the known geologic range of this species is from the Cretaceous to Recent. The living representatives of this species are known as oceanic, cosmopolitan.

The species has been found widespread in bottom-cores of different latitudes. Kolbe pointed out that *Coscinodiscus excentricus* is one of the commonest and a wide-spread species in the bottom samples throughout the Equatorial Pacific, Equatorial Atlantic, North Atlantic, and Equatorial Indian Oceans (Kolbe, 1957, p. 7).
Occurrences in the present material (Chart 6): The occurrence of this species ascertained so far in the present material was too sporadical to make itself useful to analyse the present data.

Coscinodisucs hirosakiensis Kanaya, n. sp.

Pl. 4, figs. 1, 2.

Description: Valve circular, 25–35μ in diameter, flat, slightly depressed in center, and with margin sharply defined. Valve surface competely areolated, areoleae hexagonal, fairly equisize throughout the valve surface, 6 inμ 10 except in front of the margin where they are smaller, round, 10 in 10μ along the margin. The central part of the valve bears one or a few papilleae which are distinct but smaller than ordinary areolae. Areolae fascicularly arranged, subdividing the valve surface into 7–10 sectors; areolae running parallel to the lateral longest row of each sector. No marginal spinuli present. Margin distinct with strong striae, 10 in 10μ; each striae corresponds to a small areoli arranged in a line along the inside of the striated margin.
Hclotype: IGPS coll. cat. no. 76643 (pl, 4, figs, 1a, 1b), 27.5 μ in diameter, from IGPS loc. no. Ao–12, Owasawa formation.
Paratype: IGPS coll. cat. no. 76644 (pl. 4, figs. 2a, 2b, with a connecting band

attached) 29.6μ in diameter from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks: The central papilleae, and the marginal structure of the new species reminded the writer of *Coscinodiscus nodulifer* Schmidt (Hustedt, 1928, p. 426), from which it differs in the fasciculate arrangement of areolae. In this connection, it may be added that thorough observation of *C. nodulifer* and other *Coscinodiscus* in the Equatorial Pacific deep-sea cores led Kolbe to conclude that" ··· presence or numbers of central papilleae are not always a specific character at least not with regard to certain centric forms". (Kolbe, 1954, p. 33).

Coscinodiscus vetustissimus Pantocsek (Hustedt, 1928, p. 413), and *Coscinodiscus curvatulus* Grunow var. *minor* (Ehr.) Grunow (Hustedt, *ibid.*, p. 409, fig. 217) are two forms which the new species resembles. The new species is however, distinguished from *C. vetustissimus* by finer areoleae, broader fasciculation, and by coarsely striated margin; and from *C. curvatulus* var. *minor*, by equisize areolae, absence of marginal spinculeae, and coarser and stronger striae of the margin.

Juding from the description and figures, *Coscinodiscus vetustissimus* Pant. var. *javanica* Reinhold (Reinhold, 1937, p. 102, pl. 8, figs. 7, 8), an "Upper Miocene" variety, seems to be closely related to the new species.

Occurrences in the present material (Chart 6): The species was found veryrare to rare in many samples of the Onnagawa and its correlative formations. It was found present also in the samples from the higher horizons.

Coscinodiscus lineatus Ehrenberg

Pl. 4, fig. 3.

Coscinodiscus lineatus EHRENBERG, 1840, K. Akad. Wiss. Berlin, Phys. Abh., 1838, p. 129 (inaccessible). - SCHMIDT, 1888, Atlas der Diatomaceenkunde, pl. 59, figs. 26-32, 1878; pl. 114, fig. 13, - RATTRAY, 1889, Roy. Soc. Edinburgh, Proc., vol. 16, p. 472.- HUSTEDT, 1928, Kieselalgen, Teil 1, p. 392, fig. 204. -LOHMAN, 1941, U.S. Geol. Survey Prof. Paper 196-B, p. 68, pl. 12, fig. 10 - CUPP, 1943, Bull. Scripps Inst. Oceanography, Univ. California, vol. 5, no. 1, p. 53, fig. 15. -KOKUBO, 1955, Plankton diatoms, p. 77, fig. 58. - KOLBE, 1957, Rept. Swed. deep-sea Exped., 1947–48, vol. 9, Fasc. 1, p. 29.

Size range of measured specimens: 40–80μ in diameter.

Figured specimens: IGPS coll. cat. no. 76645 (pl. 4, fig. 3), 55μ in diameter, from IGPS loc. Ak–46, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Previous records of occurrences: This cosmopolitan species has been known to occur from the late Cretaceous to Recent (Lohman, *op. cit.* p. 68).

In the west coast of North America many occurrences of this species have been reported. It is listed from the upper Cretaceous Moreno shale (Hanna, 1934, p. 355; Long *et al*, 1946, p. 103); "very abundant" in the middle Miocene (Relizian)

Sharktooth Hill deposits and from the strata of equivalent age elsewhere in the same region (Hanna, 1932, p. 180, see also Kanaya, 1957, p. 53) ; "frequent" in the Miocene of the Maria Modre Island, the West Coast of Mexico (Hanna and Grant, 1926, p. 139); and "frequent" in the Pliocene San Joaquin and Etchegoin formations at Kettleman Hills, California (Lohman, 1938, p. 82).

In eastern Java, it is also reported from the Upper Miocene and the Pliocene strata (Reinhold, 1937, p. 69 and p. 97).

This species has been found in Miocene formations of Japan (Okuno, 1952, p. 8) but never occurs frequently, so far as the present writer observed. Brun and Tempère (1889, p. 71) reported its rare occurrence in their "Calcaire de Yedo et de Sendai", exact locality and geologic age of which is still unknown.

Records of *C. lineatus* Ehr. in bottom marine sediments are numerous, and only the records of particular importance are herein cited. Lohman found (1941, *l. c.*) that the species are "rare to common" in various horizons of the North Atlantic deep-sea cores, Pleistocene and Recent.

The common occurrences of this species in the equatorial cores of the Pacific, Atlantic, and Indian Oceans are well manifested in Kolbe's table (1957, p. 7, table 2), where species stands, throughout the three oceans, at seventh in frequencies among diatom species of the bottom cores. The fact may suggest that the high frequency of this species in a diatom thanatocoenosis indicates that its accumulation had taken place under the prevalance of tropical or subtropical waters, rather than of temperate or cold ones.

Occurrences in the present material (Chart 6 :): The species was found present in the samples from the Onnagawa and its correlative formations, as well as in the ones from the higher horizons.

Coscinodiscus marginatus Ehrenberg

Pl. 4, figs. 4–6

Coscinodiscus marginatus EHRENBERG, 1843, K. Akad. Wiss. Berlin, Phys., Abh., 1841, p. 142 (inaccessible) - EHRENBERG, 1854, Mikrogeologie, pl. 18, fig. 44; pl. 33, fig. X-13, pl. 38B, fig. XXII-8. - SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 62, figs. 1-4, 9, 11, 12 (unnamed). - RATTRAY, 1889, Roy. Soc. Edinburgh, Proc., vol. 16, p. 509. - DE TONI, 1894, Sylloge algarum, p. 1241. - HUSTEDT, 1928, Kieselalgen, Teil 1, p. 416, fig. 223. - LOHMAN, 1941, U.S. Geol. Survey, Prof. Papers 196-B, pt. 3, p. 71, pl. 14, figs. 1, 6. - CUPP, 1943, Scripps Inst. Oceanography, Univ. California, Bull., vol. 5, no. 1, p. 55, fig. 19, pl. 1, fig. 3. - KANAYA, 1957, Sci. Rep. Tohoku Univ., 2d ser. (Geology), vol. 28, p. 87, pl. 6, figs. 1a, 1b.

Coscinodiscus fimbriatus-limbatus Ehrenberg, EHRENBERG, 1854, Mikrogeologie, pl. 19, fig. 4.

Coscinodiscus robustus Greville, SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 62, fig. 5 (this figure only).

Coscinodiscus subconcaves Grunow forma *major* ? SCHMIDT, 1878, ibid., pl. 62, fig. 7.

Coscinodiscus radiatus Ehrenberg forma *heterostricta* Grunow, PANTOCSEK, 1886, Foss. Bacill.

Ungarns, Teill, pl. 20, fig. 184.

Coscinodiscus radiatus Ehrenberg var. *subaequalis* (Grunow) forma *parva* PANTOCSEK, 1886, *ibid.*, pl. 22, fig. 203.

Size range of measured specimens : 40–200μ in diameter.

Figured specimens : IGPS coll. cat. no. 76647 (pl. 4, figs. 5a, 5b), 47.9μ in diameter, IGPS coll. cat. no. 76646 (pl. 4, figs. 4a. 4b), 86.5μ in diameter, both from IGPS loc. no. Ak–48–1,; IGPS coll. cat. no. 76648 (pl. 4, fig. 6), 175μ in diameter, from IGPS loc. no. Ak–49, all of the Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks : Previous records of occurrences indicate that this species has a long geologic range, from late Cretaceous to Recent (Kanaya, 1957, *op. cit.*).

From the Miocene marine diatomaceous rocks of Japan, the species has been reported frequently. It is worth mentioning that the species sometimes is excessively frequent in the diatom assemblages of these rocks, as Okuno found in a sample from the Iizuka formation, Noto Peninsula, Ishikawa Pref. (Okuno, 1952, p. 9, about 10% in relative abundance), and in a sample from the Oki Island, Shimane Pref. (Okuno, 1952, p. 15; 20–40%). The present paper includes a few localtites where *C. marginatus* Ehr. constitutes more than 50 percent of the diatom assemblages in relative abundance.

In his paper on the North Atlantic deep-sea cores, Lohman once remarked that the species ".... occurs today in all warm to temperate seas" (Lohman, 1941, p. 72). To this it should be added that the species also widely distributes in boreal to cold waters, since Jousé recently reported the species as of qualitatively abunbant species in the bottom sediments of the sea of Okhotsk (Jousé, 1957, p. 178). Contrasting to this, the species was not mentioned in Kolbe's papers on the equatorial deep-sea cores of Atlantic (1956) and Indian Oceans (1957). The frequent occurrence of this species only in his Core 76 of the Equatorial Pacific let Kolbe to have remarked that "as the core [76] its particularly rich in Pre-Quaternary species it is possible that the form was more abundant in the Equatorial Pacific during the Plicocene than that it is at present." (Kolbe, 1954, p. 33).

Occurrences in the present material (Chart 6) : Sporadical outbreaks of this species often coincide with the disappearance of the diatom asssemblage B (*Coscinodiscus Yabei* assemblage) in the sequence of the Onnagawa formation (Chart 7). It gets extermely abundant, comprising in number as high as 90 percent of an assemblage, in a few samples containing the assemblage C, but it is at the higher horizons where the species becomes consistent and common.

Coscinodiscus oculus-iridis Ehrenberg

Pl. 4, fig. 7.

Coscinodiscus oculus-iridis EHRENBERG, 1841, K. Akad. Wiss. Berlin, Phys., Abh., 1839, p. 147 (inaccessible) - EHRENBERG, 1854, Mikrogeologie, pl. 18, fig. 42; pl. 19, fig. 2. - SCHMDTT, Atlas der Diatomaceenkunde, pl. 63, figs. 6. 7. 9; 1888, *ibid.* pl. 113, figs. 1, 3, 5, 20. - RATTRAY, 1889, Roy. Soc. Edinburgh, Proc., vol. 16 p. 559. - DE TONI, 1894, Sylloge algarum, p. 1275. - HUSTEDT, 1928, Kieselalgen, Teil 1, p. 454, fig. 252. - CUPP, 1943, Scripps Inst. Oceanography. Univ. California, Bull., vol. 5, no. 1, p. 62, fig. 26, pl. 3, fig. 2. - KANAYA, 1957, Sci. Rep Tohoku Univ., 2d ser. (Geology), p. 90, pl. 6, fig. 9.

Coscinodiscus centrales Ehrenberg, EHRENBERG, 1854, Mikrogeologie, pl. 21, fig. 3 (this figure only).

Coscinodiscus oculus iridis Ehrenberg, var. *genuina* GRUNOW, 1884, K. Akad. Wiss. Wien, Denkschr., Math. - Naturw. Kl., vol. 48, p. 77.

Size range of measured specimen:s 100–150+μ in diameter.

Figured specimen: IGPS coll. cat. no. 46649 (pl. 4, fig. 7), 114μ in diameter, from IGPS loc. no. Ak-55, Shinzan diatomaceous mudstone member, Onnagawa formation.

Previous records of occurrences: The previous records indicates that the species has a long geologic range from the late Eocene to Recent (Kanaya, 1957, *l. c.*). Hustedt stated that the species is "Im ozeanishen Plankton all Meere verbreitet und häufig.". (Hustedt, *l.c.*). The species is the qualitatively abundant species in the bottom sediments of the Sea of Okhotsk (Jousé, 1957, p. 179, pl. 4, fig. 5); while it seems to have been much rarer in the equatorial deep-sea cores of Pacific, Atlantic and Indian Oceans (Kolbe, 1954, p. 34; 1956, p. 170;1957, p. 31, respectively).

Occurrences in the present material (Chart 6): This large *Coscinodiscus* was found in fragments in most cases. Its occurrences are neither consistent nor particular at a certain horizon to make thespecies dependable to analyse the present data.

Coscinodiscus radiatus Ehrenberg

Pl. 5, fig. 1.

Coscinodiscus radiatus EHRENBERG, 1841, K. Akad. Wiss. Berlin, Phys. Abh., 1839, p. 148, pl. 3, figs. 1a-c (inaccessible). - SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 60, figs. 5, 6, 9, 10; pl. 61, fig. 13 (unnamed); pl. 65, fig. 8 (unnamed). - RATTRAY, 1889, Roy. Soc. Edinburgh, Proc., vol. 16, p. 514. - DE TONI, 1894, Sylloge algarum, p. 1244. - HUSTEDT, 1928, Kieselalgen, Teil 1, p. 420, fig. 225. - LOHMAN, 1941, U.S. Geol. Survey, Prof. Papers 196-B, p. 73, pl. 15, figs. 7, 8. - CUPP, 1943, Scripps Inst. Oceanography, Univ. California, Bull., vol. 5, no. 1, fig. 20; pl. 1, fig. 4.

Coscinodiscus devius SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 60, figs. 1-4.

Coscinodiscus radiatus Ehrenberg var. *subaequalis* GRUNOW, 1884, K. Akad. Wiss. Vien,

Denkschr., Math. - Naturw. Kl., vol. 48, p. 72, pl. III, fig. 3.
Coscinodiscus radiatus Ehrenberg var. *borealis* GRUNOW, 1884, *ibid.*, vol. 48, p. 72, pl. III, fig. 1.
Coscinodiscus radiatus Ehrenberg var. *media* GRUNOW, 1884, ibid., vol. 48, p. 72, pl. III, fig. 2.

Size range of measured specimens; 50-100 μ in diameter.

Figured specimens: IGPS coll. cat. no. 76651 (pl. 5' fig. 1), 96 μ in diameter, from IGPS loc. no. Ak-48-5, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: It is not always easy to draw a line between *Coscinodiscus argus* Ehr. and *Coscinodiscus radiatus* Ehr., although the differece is evident in typical specimens. The specimen figured (pl. 5, figs. 1a, 1b) is an example of a difficult specimen to decide. It can not be *Coscinodiscus obscurus*, since the intersticial meshes are lacking.

Previous records of occurrences: The previous records indicate that this species has a long geologic range, late Eocene to Recent (Kanaya, 1957, p. 92). The present writer found this species in most of the Japanese Miocene, Pliocene, and Plesitocene marine diatomaceous rocks examined, but it is never frequent.

The living representative of this species has a world-wide distribution. Whether the distribution is rather confined to "warm to temperate seas" as Lohman suggested (Lohman, 1941, *op. cit.*) is open to question.

Occurrences in the presentmaterial (Chart 6): In the present material, the species occurred always with low frequencies, and never became particularly often, or consistently absent at certain horizons.

Coscinodiscus Rothii (Ehrenberg) Grunow

Pl. 5, fig. 2.

Heterostephania Rothii EHRENBERG, 1854, Mikrogeologie, Taf. XXXV A, Fig. XIII 8 b, 4, 5. Locality: Elbe Tertiary mud.
Coscinodiscus symmetricus Kitton, Weissflog, in SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 57, figs. 25-27 (not Greville, 1861).
Coscinodiscus Rothii (Ehrenberg) GRUNOW, 1878, in SCHNEIDER, Natur. Beitr. Z. Kennt. der Kaukasuslander, p. 125 (inaccessible). - GRUNUW, 1884, K. Akad. Wiss. Wien, Denkschr. vol. 48, p. 81, pl. 3, figs. 20a, 20b, 22. - RATTRAT, 1889, Roy. Soc. Edinburgh, Proc., vol. 16, p. 502. - HUSTEDT, 1928, Kieselalgen, Teil 1, p. 400, fig. 211.
Coscinodiscus subtilis var. *Rothii*, 1885, VAN HEURCK, Syn. diatom. Belgique, p. 218.

Size range of measured specimens: 40-60μ in diameter.

Figured specimens: IGPS coll. cat. no. 76652 (pl. 5, fig. 2), 42μ in diameter, from IGPS loc. no. Ak-59, Shinzan diatomaceous mudstone member, Onnagawa formation.

Previous records of occurrences: Rattray's (*l. c.*) list of previous occurrences includes those from the so-called "Oamaru", "Barbados," and "Richmond, Virginia", suggesting that the species has been found in Tertiary strata, as old as late Eocene in age (Kanaya, 1956, pp. 53–55). Hustedt (*l. c.*) stated that the species is "in allen Meeren verbreitet und meist häufig".

Occurrences in the present material (Chart 6): Found only occasionally in the Japanese Miocene material here studied.

Coscinodiscus Temperei Brun

Pl. 4, Fig. 8.

Coscinodiscus Temperei, BRUN, in BRUN and TEMPÈRE, 1889, Soc. Phys. et d'Hist. Natur. Genève, Mém., tome 30, no. 9, p. 33, pl. 8, fig. 2. Locality: "Calcaire de Sendai et de Yédo". - DE TONI, 1894, Sylloge algarum, p. 1255.

Size range of measured specimens: 30–70μ in apical axis.

Figured specimens: IGPS coll. cat. no. 76653 (pl. 4, fig. 8), apical axis 48.5μ, transapical axis 33μ, from IGPS loc. no. Ao–13, Owasawa formation.

Remarks: The diagnostic features of this species are 1) broad ellipsoidal valve with a plication, the axis of which is in parallel to the apical axis, 2) radially arranged areolae, 5–7 in 10μ, which, running from a central part of the valve situated on the axis of plication, forms a complete meshwork on the valve surface, and 3) presence of marginal spines 3–4 in 10μ, and a distinct central spine.

The specimens being referred have all the appearance of Brun's species, except, the central spine is inconspicuous, and valves are smaller than what Brun described for the species, 60–85μ in apical axis (Brun and Tempère, *l. c.*).

Previous records of occurrences: Recorded so far only from its type material, geologic age and locality of which have not been ascertained. Brun remarked that "Ce *Coscinodiscus* est une des especes typiques de calcaires japonais...." (Brun, *op. cit.*, p. 34).

Occurrences in the present material (Chart 6): Found very rare in a few samples from the Onnagawa formation, one from the uppermost part of the Owasawa formation, as well as in a sample from the higher horizon, Ao–24 of the Maido fromation. The previous record suggests that the species has a certain stratigraphic value, which, however, was not apparent in dealing with the Miocene material alone.

Coscinodiscus vetustissimus Pantocsek

Pl. 5, figs. 3–5.

Coscinodiscus vetustissimus PANTOCSEK, 1886, Foss. Bacill. Ungarns, Teil I, pl. 73, pl. 20, fig. 186. Locality: "St. Peter", Hungary. -RATTRAY, 1889, Roy. Soc. Edinburgh, Proc., vol. 16, p. 477. - DE TONI, 1894, Sylloge algarum, p. 1220. - HUSTEDT, 1928, Kieselalgen, Teil 1, pp. 412–414, fig. 220.

Size range of measured specimens : 45–80μ in diameter.
Figured specimens : IGPS coll. cat. no. 76654 (pl. 5, fig. 3), 59.5μ in diameter, from IGPS loc, no. Ao–10, Owasawa formation ; IGPS coll, cat. no, 76655 (pl. 5, fig, 4), 52.5μ in diameter, from IGPS loc. no. Ao–13, Owasawa fromation; IGPS coll. cat. no. 76656 (pl. 5, fig. 5), 80μ in diameter, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation.
Remarks : The present identification is made by referring to Hustedt's diagnosis of the species, which the writer believes is the most comprehensive. The present specimens, however, have the hyaline ring less distinct than that figured by Hustedt (*l. c.*).

The principal difference of this species from *Coscinodiscus curvatulus* Grunow is the presence of a distinct central papilli, which was always found on the specimens here identified with *C. vetustissimus*. Narrower, and less distinct fasciculation than that described for *Coscinodiscus curvatulus* is another reason of the present identification.

Coscinodiscus inaequalis Grove and Sturt (1887, p. 68) has been considered as a synonym of *C. vetustissimus* by Rattray, De Toni, and Hustedt. However, by its finer areolae, described to be 10–12 in 10μ, than 4.5–5 in 10μ of *C. vetustissimus*, the writer believes that the two forms are better to be distinguished.
Previous records of occurrences : The type locality (Pantocsek, *l. c.*) was St. Peter deposit of Hungary, which according to Forti is of the Helvetian Stufe (Pia in Hirmer, 1927. p. 46). The species was found to be the characteristic one of the upper part of the Pliocene Etchegoin formation, Kettleman Hills, California (Lohman, 1938, p. 86, pl. 20, fig. 7.). Hustedt who concluded that Cleve's records of *C. vetustissimus* in the Recent materials were based on misidentification of the species for *C. nodulifer*, doubted whether the species is still living (Hustedt, *l. c.*).
Occurrences in the present material (Chart 6) : In the Onnagawa formation, the species tends to occur more often in the assemblages A and B, than in the assemblage C, and becomes frequent at two samples of the assemblage B. The species has considerable occurrences in the samples from the Yorionobezawa and Owasawa formations, whereas it became much rare, if not totally lacking, in the samples of the higher horizons.

The occurrence of this species alone does not mean much stratigraphically. It is inferred statistically, however, the species plays a role as a marker species of the assemblage, with the other seven species, to form the particular joint occurrences which distinguish the assemblage B (*Coscinodiscus Yabei* assemblage) from the others (Chart 7).

Coscinodiscus Yabei Kanaya, n. sp.

Pl. 5, figs. 6–9.

Description: Valve circular, 25–50μ in diameter, surface with a tangential plication, on one side concave, on the other convex. Central area absent. Areolae polygonal, radially arranged in a complete meshwork throughout the valve surface. Areolae 6–7 in 10μ near center, slightly increased in their size outwardly, up to 4–6 in 10μ, and again decrease at the submarginal border. Secondary spiral sculpture of areolae well developed, but interrupted by the axis of plication. Margin clearly defined, flat, rather broad, 2.5–4μ in breadth, radially striated with extensions of chamber walls of the areolae at the outer ends of the radial rows. With a hyaline marginal rim, a pair of the marginal striae makes a petal-shaped structure between which the valve margin is crenuated; crenulation 4–5 in 10μ. Marginal spines absent.

Holotype: IGPS coll. cat. no. 76657 (pl. 5, figs. 6a, 6b, 6c), 28.5μ in diameter, from IGPS loc. no Ao–12, Owasawa formation.

Paratypes: IGPS coll. cat. no. 76658 (pl. 5, figs. 7a, 7b, 7c), 30μ in diameter, from IGPS loc. no Ao–12, Owaswa formation; IGPS coll. cat. no. 76659 (pl. 5, fig. 8), 43.2μ in diameter; IGPS coll. cat. no. 76660 (pl. 5, fig. 9), 47μ in diameter, the latter two from IGPS loc. no. Ak–46, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: In more than 50 specimens carefully examined, the type of plication was consistent: separated by the straight axis, one side the plication is concave, the other side is convex, and both are semicircular in outline. Such a type of plication, and radial arrangement of areoleae in closed meshwork suggest that the new species is to be placed near to an extinct species, *Coscinodiscus plicatus*, which belongs to the morphological series of plicated *Coscinodisci*. *C. lacustris* var. *hyperborea* Grunow, *C. lacustris* var. *septentrionalis* Grunow, and *C. lacustris* Grunow are the other members of this series which were said to be morphologically united through gradual transition (Kolbe, 1954, p. 34).

On the figures of *C. plicatus* Grunow given by Grunow (1884, pl. 3, fig. 10) and Schmidt (1878, pl. 58, fig. 1), the valve margin was not clearly defined. Neither Grunow and Schmidt, nor Kolbe (*op. cit.*) particuarly mentioned about the marginal structure of the species. The new species is distinguished from *C. plicatus* in having the clearly defined crenulated margin, together with a coarse areolation still coarser than that of *C. plicatus* which was the most coarsely areolated species among the plicated *Coscinodisci* mentioned above. Lacking of marginal spines may be another difference of the new species from the other plicated *Coscinodisci*.

The new species is named for Dr. Hisakatsu Yabe, Professor Emeritus of the Tohoku University.

Occurrences in the present material (Chart 6) : The species was restricted to the assemblage B in the Onnagawa formation, and, by its fairly consistent occurrences in the assemblage it has been chosen as the index for which the assemblage is named (Chart 7). All samples from the Yorinobezawa and Owasawa formations carry this species, except one, Ao–13, from the uppermost dortion of the Owasawa formation.

Subfamily Actinodiscoideae Schütt 1896

[as Actinodisceae; emend. Karsten, 1928]

Tribe Stictodisceae Schütt, 1896

[as Stictodiscinae; emend. Karsten, 1928]

Genus ***Cladogramma*** Ehrenberg, 1854

Cladogramma calimornicum Ehrenberg

Pl. 6, fig. 1.

Cladogramma californicum EHRENBERG, 1854, Mikrogeologie, (inaccessible) - VAN HEURCK, 1881, Synopsis diatom. Belgique, pl. 83 bis., figs. 8, 9. - DE TONI, 1894, Sylloge algarum, p. 1422.

Size range of measured specimens: 25–35μ in diameter.

Figured specimen : IGPS coll. cat. no. 76625 (pl. 6, fig. 1), 30μ in diameter, from IGPS loc. no. Ao–13, Owasawa formation.

Remarks : The specimens in the present samples are identical with one of Van Heurck's figure (*l. c.* fig. 8), which was later accepted in De Toni's check list (*op. cit.*) as an illustration of the species. Specimens bearing "Stachel" as was shown by another Van Heurck's figure (*l. c.*, fig. 9) were not found in the present samples.

The species resembles *Cladogramma jordani* Hanna, an upper Cretaceous species, (Hanna, 1927b, p. 16, pl.2, fig. 1), from which it differs in the raised center, broader hyaline margin, and by radial striae coarser and straight. From another similar form, *Cladogramma scandina* Cleve-Euler (Cleve-Euler, 1941, p. 179, pl. 2, fig. 1), the species is distinguished in having a smaller central plate, and coarser striae.

Remarks : According to Hanna (1927b, p. 17), Ehrenberg's specimen came from "a deposit of Monterey (Miocene) shale from San Francisco". The Van Heurck's figures bearing a remark as from "Dépôt de Monterey" may be of the specimens from the same source, probably the Miocene in age.

Occurrences in the present material (Chart 6) : The species occurred only sporadically in the present material.

Genus ***Arachnoidiscus*** Ehrenberg, 1850

Arachnoidiscus Ehrenbergii Bailey ex Ehrenberg

Pl. 6, figs. 2, 3.

Arachnoidiscus Ehrenbergii Bailey in EHRENBERG, 1850, Akad. Wiss. Berlin, Ber. 1849, p. 63 (inaccessible). -SCHMIDT, 1886, Altlas der Diatomaceenkunde, pl. 68, fig. 1. -DE TONI, 1894, Sylloge algarum, p. 1311. -HUSTEDT, 1929, Kieselalgen, Teil 1, p. 471, fig. 262. -CUPP, 1943, Scripps Inst. Oceanography, Univ. California, Bull., vol. 5, no. 1, p. 66, fig. 28. -KOKUBO, 1955, Plankton diatoms, p. 98, fig. 87.

Arachnodiscus Ehrenbergii var. *californica* SCHMIDT, 1878, Atlas der Diatomaceenkunde, pl. 68, figs. 3, 4; pl. 73, fig. 1.

Hemiptychus Ehrenbergii MANN, 1907, U.S. Natl. Herbarium. Contr., vol. 10, pt. 5, p. 267.

Size range of measured specimens : 90–180μ in diameter.

Figured specimens : IGPS coll. cat. no. 76621 (pl. 6, fig. 2), 93.5μ in diameter, from IGPS loc. no. Ao–9, Owasawa formation; IGPS coll. cat. no. 76622 (pl. 5, fig. 3), 176μ in diameter, from IGPS loc. no. Ao–13, Owasawa formation.

Remarks : Under this species here included are *Arachnoidiscus* with primary radial ribs penetrating from margin to an outer circle of the central area; with the central area clearly defined where a double concentric rows of areolae are present; with areolae regularly arranged in concentric rows over the valve surface, short partitions of the rows in each sector meet opposite to those of neighbouring sectors; and with short secondary radial ribs extending inwardly beyond the marginal chambered ring. The appearance of the central area is extremely variable : the areolae of the outer concentric row round or subangular; the areolae of the inner row usually elongated, often in wedge shape tapering inwardly, or in short rod-shape arranged radially. Beside the typical form, specimens almost identical with Schmidt's figure of *Arachnoidiscus Ehrenbergii* var. *californica* Schmidt (*l. c.*) are also found in the present materials (see pl. 6, fig. 2). Since Schmidt did not describe the variety characteristic, and since, as Reinhold once stated (Reinhold, 1937, p. 80), one will always find a new transitional form between this group of *Arachnoidiscus*, the present writer did not distinguish the Schmidt's variety as a spearate one while examining the present samples.

Previous records of occurrences : A record from the upper Cretaceous Moreno shale (Long *et. al.*, 1946, p. 95, pl. 13, fig. 6) is excluded from the present discussion, because the figure given, seems to the present writer, is not of this species.

Schmidt's figure of var. *californica* was of specimens from "San Francisco" (Schmidt, *l. c*,), but no further information about the source is available : Probably of Miocene in age. Lohman reported the species from the Pliocene San Joaquin formation at Kettleman Hills, California (Lohman, 1938, p. 53).

The ocurrences of this species in Miocene marine formatoins of the Japan Sea coast have been reported by Ichikawa (1950, p. 53), and Okuno (1952b, p. 8-9). According to Brun and Tempère, the species was found rare in their "Calcaire de Yédo et de Sendai", exact locality and geologic age of the material are still unknown.

Mann (1907, p. 267) found this species in the bottom samples from 15 Pacific stations. The stations are distrubuted in the area between 45°25′00″ to 56°56′00″ N. Lat., through the Bering Sea, off the Aleutian Islands, off British Cloumbia, the Sea of Okhotsk and off Honshu Island, ranging in depth from 56-1866 fathoms. Except one station, 4313 F off Inubo-zaki, Honshu Island where the surface water temperature was 22°C when occupied in June, these stations were of rather lower surface temperature, ranging from 6°C to 15°C when occupied during the period of June to September.

In this connection, it might be mentioned that the species was not reported in Kolbe's works on diatoms in the deep-sea cores under the equatorial belt of the Pacific, (1954), Atlantic (1956), and Indian (1957) Oceans.

Living representative of this speices is known to be of a bottom form fixed on the algae in the littoral zone, but is also occasionally found in the plankton (Cupp, *l.*c,) . Hustedt stated (*l.c*) that the species is widely and abundantly distributed, especially forming a colony with Ithsimas, along the Pacific coast of Asia and America. He doubted its distribution in the European seas.

Occurrences in the present material (Chart 6) : So far as the writer examined, the diatom assemblages A and B of the Onnagawa formation were barren of this species. The species occurred in some of the samples of the Yorinobezawa and Owasawa formations, as well as in those from the upper horizons, but was always very rare to rare.

Tribe Actinoptycheae

[as Actinoptychineae; emend Karsten 1928]

Genus Ehrenberg, ***Actinoptychus*** 1843

Actinoptychus senarius (Ehrenberg) Ehrenberg

Pl. 6, figs. 4, 5.

Actinoptychus senarius EHRENBERG, 1838, Die Infuscionstherchen als vollkommene Organismen, p. 172, pl. 21, fig. 6. Locality: "Polierchiefer von Oran" Africa.

Actinoptychus senarius (Ehrenberb) EHRENBERG, 1843, K. Akad. Wiss. Berlin, Phys. Abh., 1941, p. 400, pl. 1, fig. 27 (inaccessible). -LOHMAN, 1941, U.S. Geol. Survey, Prof. Paper 196-B, p. 80, pl. 16, fig. 9, with comprehensive list of synonyms.

KANAYA, 1957, Sci. Rep. Tohoku Univ., Japan, 2d. ser. (Geology), vol. 28, p. 98, pl. 7, fig. 17.

Actinoptychus undulatus (Bail ?) Ralfs, DE TONI, 1894, Sylloge algarum, p. 1372.

Actinoptychus undulatus (Bail.) Ralfs, HUSTEDT, 1929, Kieselalgin, Teil 1, p. 475, fig. 264. - OKUNO, 1952, Bot. Mag., Tokyo, vol. 65, no. 158, p. 14, pl. 1, fig. 3a-3'. (electron microscopical study). - KOKUBO, 1955, Plankton diatoms, p. 99, fig. 89.

Size range of measured specimens: 35–60μ

Figured specimens: IGPS coll. cat. no. 76618 (pl. 6, figs. 4a, 4b), 55μ in diameter, from IGPS loc. no. Ao–9, Owasawa formation; IGPS coll. cat. no. 76619 (pl. 6, fig. 5), 35.7μ, from IGPS loc. no. Ao–12, Owasawa formation.

Remarks: The present writer follows Lohman (1941 *l.c.*) in accepting Hendy's claim (Hendy, 1937, cited in Lohman) that the name *Actinoptychus senarius* (Ehrenberg) Ehrenberg haspriority over *Actinoptychus undulatus* (Bailey) Ralfs and therefore the latter name, which has been widely used in diatom literatures is not valid. For a complete list of synonyms, the readers are referred to Lohman (1941 *l.c.*). *Actinoptychus senarius* in the present samples always had 6 sectors.

Previous records of occurrences: The geologic range of this species is known to be from late Eocene to Recent (Lohman, *l.c.*; Kanaya, *op. cit.* p. 99). The previous works on Japanese materials (e.g. Brun and Tempère, 1889, p. 68; Ichikawa, 1950, p. 43; Okuno, *op. cit.*, p. 8), as well as the personal experience of the present writer, found that the species is ubiquitous in the Japanese Miocene, Pliocene, and Pleistocene diatomaceous rocks of marine origin.

Mann (1907, p. 272) found this species in the bottom samples from various areas of the Pacific, covering the Galapagos Islands to the Bering Sea and off Honshu Island, ranging from the tropical to boreal waters. Recent works by Kolbe proved that the species is distributed in Pleistocene and Recent deposits throughout the equatorial Pacific, Atlantic, and Indian Oceans, though never frequent (Kolbe, 1954, 1956, 1957.)

The living representatives of this species are known to be of neritic, bottom form, frequently found in plankton (Cupp, *l. c.*), and Hustedt remarked that the species "Im Küstengebiet, selten im Küsten-plankton, aller Meeres verbreitet und häufig, auch hier und da in die Flüssmündugen hineingehend. Im Mittelmeeresgebiet weniger zahlreich als an den nördlichen Küsten Mitteuropas." (Hustedt, *op. cit.*, p. 476). The species was reported to be more common in December and January than the other months of the year in Mutsu Bay, Aomori Prefecture, Northern Honshu, Japan (Kokubo, *l. c.*).

By the records cited above, it appears that *Actinoptychus senarius* has little value as a chronological, or an ecological indicator, except that the high frequency of this species in a diatom thanatocoenosis would suggest rather neritic origin of sediments than oceanic.

Occurrences in the present material (Chart 6) : The species was found very rare to common in most of the samples of the Onnagawa, Yorinobezawa, and Owasawa formations, as well as in the samples from the higher horiozns.

Actinoptychus cfr. ***splendens*** (Shadb.) Ralfs var. ***Halionyx*** Grunow ex Van Heurck

Pl. 6, fig. 6.

Actinoptychus Halionyx GRUNOW, Alg. Novara, p. 25, date of publiscation unkown. (inaccessible)

Actinoptychus splendens (Shadb.) Ralfs var. *Halionyx* Grunow, VAN HEURCK, 1881, Synopsis diatom. Belgique, pl. 119, fig. 3, pl. 120, fig. 3. - DE TONI, 1894, Sylloge algarum, p. 1386, - REINHOLD, 1937, Nederland en Kolonien Geol. Mijinb. Genoot. Verh., Geol. Ser., vol. 12, p. 79, pl. 13, fig. 1.

Figured specimen : IGPS coll. cat. no. 76620 (pl. 6, fig. 6), 72.5μ in diameter, from IGPS loc. no. Ao–13, Owasawa formation.

Remarks : The figured specimen is identical with a figure of Van Heurck (*l.c.*, pl. 119, fig.3) who first illustrated the variety. The specimen has punctation (of outer membrane ?) of both sectors similar, 9–10 in 10μ, being in decussating oblique rows and parallel radial rows. The raised sectors narrower, and with a hyaline line on each sector, running from the marginal process towards the inner end of valve center. The depressed sectors wider, with no hyaline line nor the marginal process. Coarser structure of inner membrane is observed in the raised sectors.

The specimen studied lacks the hyaline bracket-shaped region in front of valve margin, the presence of which on depressed sectors characterizes *Actinoptychus splendens* and its varieties. Ven Heurck's first figure (pl. 119, fig. 3, *l.c.*) does not, and his second figure (pl. 120, fig. 3) does have, though narrow, the hyaline bracket-shaped regions. De Toni (*op. cit*). accepted the both figures as of the lectotypes of the variety.

Reinhold's figure (*l.c.*) which has raised and depressed sectors in approximately equal width, also has the narrow marginal hyaline regions in front of the depressed sectors.

Van Heurck did not give the description of the variety, but his placing of this variety under *Actinoptychus splendens* suggests that in his conception the variety was an *Actinoptychus* with the bracket-shaped regions. De Toni's treatment of the variety as of *A.splendens* seems to support this assumption.

If the lacking of such a structure on diatoms here tentatively referred to variety *Halionyx* will be confirmed by examining more Japanese specimens, they should be, including the first figure of Van Heurck (*op. cit*), distinguished from

Actinoptychus splendens and its varieties in the current sense.
Previous record of occurrence: Van Heurck's second figure (pl. 120, fig. 3) was from "Guano de Peron"; his first figure lacked the remark about its source. Reinhold remarked that the variety was restricted to have occurred in the Wanosari-series, in Java, "Middle Miocene" (Reinhold, *l.c.*).
Occurrences in the present material (Chart 6): The variety was only found at sample Ao–13, from the uppermost portion of the Owasawa formation.

Tribe Asterolamprieae Schütt, 1896

[as Asterolamprinae; emend. Karsten, 1928]

Genus ***Asteromphalus*** Ehrenberg, 1845

Asteromphalus moronensis (Greville) Rattray

Pl. 6, fig. 7.

Asterolampra moronensis GREVIELE, 1863, Quart. Jour. Micr. Sci., n. ser., vol. 3, p. 230, pl. 9, fig. 8. Locality: "Deposit at Moron, in the Province of Seville", Spain.
Asteromphalus moronensis (Greville) RATTRAY, 1890, Roy. Soc. Edinburgh, Proc., vol. 16, p. 659. - SCHMIDT, 1886, Atlas der Diatomaceenkunde, pl. 38, fig. 24 (a mere application of the new combination of the name). - DE TONI, 1894, Sylloge algarum, p. 1412.

Size range of measrued specimens: 80–120μ in diameter.
Figured specimen: IGPS coll. cat. no. 76623 (pl. 6, fig. 7), 43.5μ in radius an incomplete specimen, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation.
Remarks: Although no complete specimen was found in the samples studied, the structure of the central part preserved in most of the specimens made the present identification possible.

On Greville's original figure, the radial umbilical lines connect a central point and segments, and only these lines from two segments, between which hold the narrower ray, join at a half distance to the center.

On the present specimens, however, other lines than those from the particular two segments, also join at a short distance before reaching the center; the feature shown in the Schmidt's figure (*op. cit.*).

An angular bent of umbilical lines, which is a species characteristic of *A. moronensis* and is distinctly shown on both Greville's and Schmidt's figures, is far less pronounced on the specimens studied. In despite of this, they can be distinguished from other *Asteromphalus* by the following characters, namely: 1) the one narrower ray corresponds to the rather simple structure, made by approximated two umbilical lines from neighboured segments, and 2) inner ends of sectors are obliquely truncated, straight or slightly concave toward the center.

Asteromphlus dubius, described by Hanna and Grant from Miocene deposit of the Maria Madre islands (Hanna and Grant, 1926, p. 126, pl. 13, fig. 2), is undoubtedly related to the present species particularly to the Japanese specimens here concerned in the arrangement of the umbilical lines.

Previous records of occurrences : According to Pia (in Hirmer, 1927, p. 46), the age designation of "deposit at Moron", the type locality, to the Aquitanian is of doubt. Rattray (*op. cit.*) cited a record from "Santa Monica", but the locality and geologic age of the sample are indeterminable (Hanna, 1936, p. 110.) Probably of Miocene in age.

Occurrences in the present material (Chart 6) : The species occured sporadically in the present material, and were very rare to rare, except in sample Ak–70–5 from the Yorinobezawa formation, where it was frequent.

Subfamily Eupodiscoideae Schütt, 1896

[as Eupodisceae; emend. Karsten, 1928]

Tribe Aulacodisceae Schütt, 1896

[as Aulacodiscinae; emend. Karsent, 1928]

Genus ***Aulacodiscus*** Ehrenberg, 1845

Aulacodiscus amoenus Greville

var. ***hungaricus*** Pantocsek

Pl. 6, fig. 8.

Aulacodiscus amoenus Greville var. *hungaricus* PANTOCSEK, 1886, Foss. Bacill. Ungarns, Teil 1, p. 57, pl. 2, fig. 13. Locality : "Szent Peter", Hungary. - RATTRAY, 1888, Roy. Micr. Soc. London, Jour., vol. 8, p. 375. - DE TONI, 1894, Sylloge algarum, p. 1109.

Figured specimen : IGPS coll. cat. no. 76624 (pl. 6, figs. 8a, 8b) 100μ in diameter, partly broken, from IGPS loc. no. Ao–13, Owasawa formation.

Remarks : Individuals in the present samples of the Japanese Miocene are identified with var. *hungaricus*, because the areolae in the outer half of radius are finer (5–6 in 10μ) than that described for the species (for species, see Greville, 1864, p. 10, pl. 1, fig. 3; Rattray, 1888, p. 375; and Schmidt, 1875, pl. 34, fig. 6, pl. 41, fig. 13). Rather irregular arrangment of round areolae in the inner half of radius where they become sparse, is another reason of this identification.

Previous record of occurrence : Previously found only from its type locality, Szent Peter, Hunagry (Pantocsek, *op. cit.*), which according to Pia of "Miozän, nach Forti Helvetische Stufe" (Pia, 1927, p. 46).

Occurrences in the present material (Chart 6) : Found only in sample Ao–13 from the uppermost part of the Owasawa formation, and in a sample of the higher horizon, sample Ao–27, of the Matazawa formation.

Tribe Eupodisceae Schütt, 1896

[as Eupodiscinae; emend. Karsten, 1928]

Genus ***Actinocyclus*** Ehrenberg, 1838

Actinocyclus Ehrenbergii Ralfs

Pl. 7, fig. 1.

Actinocyclus octonarius EHRENBERG, 1838, Die Infusionsthierchen als vollkommene Organismen, p. 172, pl. 21, fig. 7 (inaccessible). - LOHMAN, 1948, Cretaceous and Tertiary subsurface geology, p. 167, pl. 8, fig. 8.

Actinocyclus Ehrenbergii RALFS, 1861, in PRICHARD, Infusoria, 4th ed., p. 834. - VAN HEURCK, 1881, Synopsis diatom. Belgique, pl. 123, fig. 7. - RATTRAY, 1890, Quekett Micr. Club, Jour., 2d ser., vol. 4, p. 171. - HUSTEDT, 1929, Kieselalgen, Teil 1, p. 525, fig. 298 (with a complete list of synonyms). - HANNA, 1932, California Acad. Sci., Proc., 4th ser., vol. 20, p. 168, pl. 2, figs. 1, 2, 3.

Size range of measured specimens ; 50-90μ in diameter.

Figured specimen: IGPS coll. cat. no. 76601 (pl. 7, figs. 1a, 1b), partly broken, 64μ in diameter, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks: For the classification of this common species with numerous synonyms, the present writer follows Hustedt (*l.c*·), and calls the species *Actinocylus Ehrenbergii* instead of the valid name, *Actioncylus octonarius* Ehr. (Lohman, *l.c.*). This is done by a simple reason that since the former name has been so widely used in diatom literature that the mere mentioning *Actionocyclus octonarius* will easily be taken by casual workers as a synonym of *Actinocyclus Ehrenbergii* Ralfs with 8 rows of areolae in a sector, rather as the valid name of what is commonly called *Actinocyclus Ehrenbergii.*

In the specimens examined, the valve surface is flat, never concentrically undulated; areolae are 9-11 in 10 μ; submaginal zone is narrow; pseudonodule is hyaline and distinct. Numbers of radial rows within a sector ranges from 13 to 20. The valves bear peculiar blue colour in pleurax mounting when they are observed under a low (10$\times$20) magnification, with blue filtered light.

Previous records of occurrences; Judging from the list of occurrences given in Rattray's monograph (l.*c*.), the oldest geologic occurrence of this species has been from the "Richmond" locality of Virginia which, according to the current knowled ge, of the Calvert formation, medial Miocene in age (Lohman, *op.*

cit., p. 152). Lohman illustrated a typical specimen of the species from the subsurface sample of the Calvert formation in Maryland (*l.c.*).

The species is still living, for which, Hustedt stated (*l. c.*) that "Die Art ist in allen euıopäischen Meeren sehr verbreitet und häufig, besonders in der Nahe der Küsten, fehlt aber auch selten im Plankton vollstandig". Brackish-water, and tychopelagic occurrences were added from the Scandinavian localities (Cleve-Euluer, 1952, p.81). Through his studies of deep-sea cores, Kolbe found that the typical form of this species is lacking in the equatorial Atlantic (1956. p. 164), extremely rare in the equatorial Pacific cores (1954, p. 20), while the species widely distributes in the equatorial Indian Ocean bottom cores (1957, p. 22).
Occurrences in the present material (Chart 6) : The species was found frequent in sample Ak–55, from the Shinzan diatomaceous mudstone member, Onnagawa formation ; and very rare in samples of the Yorinobezawa formation. It was also found present in a sample of the higher hoıizon, Ao-25 of the Maido formation.

Actinocyclus Ehrenbergii Ralfs
var. ***tenella*** (Bréb.) Hustedt
Pl. 7, figs. 2, 3.

Eupodiscus tenellus BRÉBISSON, 1854, Soc. Imp. Sci. Natur. Cherbourg, Mem., Bd. 2, p. 257, pl. 1, fig. 9 (inaccessible).
Actinocyclus monoliformis RALFS, 1861, in PRITCHARD, Infusoria, 4th ed. p. 834 (inaccessible). - VAN HEURCK, 1881, Synopsis diatom. Belgique, pl. 124, fig. 9. - RATTRAY, 1890, Quekett Micros. Club., Jour., 2d ser., vol. 4, p. 182. - DE TONI, 1894, Sylloge algarum, p. 1180.
Eupodiscus minutus HANTZSSCHEL, 1863, Rahb. Beitr. Kennt. Algen, H. 1, p. 21, pl. 6A, fig. 9 (inaccessible).
Actinocyclus monoliformis var. SCHMIDT, 1874, II Jahresber. Komm. Deutsch. Meere, Kiel, pl. 3, fig. 31 (inaccessible).
Actinocyclus tenella, CLEVE, 1878, Bih. Kongl. Sv. Vet. -Akad. Handl. Bd. 5, no. 8, p. 18 (inaccessible).
Actinocyclus monoliformis var. *baltica*, RATTRAY, 1890, *op. cit.*, p. 185.
Actinocyclus tenellus Brébisson, PÉRAGALLO, 1902, Diatomees France, p. 417, pl. 113, figs. 7, 8.
Actinocyclus Ehrenbergii var. *tenella* (Bréb.) HUSTEDT, 1929, Kieselalgen, Teil 1, p. 530, fig. 302.

Size range of measured specimens : 28-40μ in diameter.
Figured specimens : IGPS coll. cat. no. 76602 (pl. 7, fig. 2) 29.6μ in diameter, from IGPS loc. no. Ak-53, Shinzan diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76603 (pl. 7, fig. 3), 38.8μ in diameter, from IGPS loc. no. Ak–48–1, Hirasawa distomaceous mudston emember, Onnagawa formation.
Renarks : The variety is represented in the present samples by typical specimens. and is easily distinguished from other *Actinocyclus*. Sectors are broad, 5-6

sectors on a valve ; interfascicular rows of radial areolae are clarly manifested ; areolae extend parallel to the middle row of each sector and terminate before the interfascicular rows leaving interfascicular meshes ; submarginal zone, made by finer areolae, are well developed. A marginal pseudo-nodule is obvious on most of the specimens examined, although it is not properly illustrated in the figures given. Areolae equisize in the radial direction, 8-9 in 10μ in inner 4/5 to 5/7 of radius, and become much smaller outwardly to form submarginal zone.
Previous records of occurrences : Rattray's (1890, *l. c.*) list of occurrences even up to that date is too long to repeat, and it would be sufficient for the present purpose to only mention here that the present variety has so far been reported from many fossil localities of Noith America, New Zealand, and Hungary, ranging from late Eocene (Oamaru) to Recent.

Hustedt (1929, *l. c.*) mentioned that the variety occurs with the species, *Actinocyclus Ehrenbergii*, which according to him, is widespread and frequent in European seas, especially in the neritic zone. Kolbe reported that the variety was found in some bottom cores of the equatorial Atlantic (1956), West Pacific (1954), and Indian (1957) Oceans.
Occurrences in the present material (Chart 6) : The variety was found rare in four samples of the Onnagawa formation, two of the Yorinobezawa formation, and three of the Owasawa formation, as well as in a sample of the higher horizon, Ao-26 of the Iizume formation.

Actinocyclus ellipticus Grunow var. ***javanica*** Reinhold

Pl. 7, figs. 4, 5.

Actinocyclus ellipticus Grunow var. *javanica* REINHOLD, 1937, Nederland en Kolonien Geol. Mijinb. Genoot., Verh., Geol. ser., vol. 12, p. 75, pl. 1, figs. 7, 8. Locality : "*Globigerina*-marl (Upper Miocene)", the Megeri formation, Java.

Size range cf measured specimens : 23-53μ in apical axis.
Figured specimens : IGPS coll. cat. no. 76604 (pl. 7, fig. 4), apical axis 52.5μ, transapical axis 34μ, from IGPS loc. no. Ak-56, Shinzan diatomaceous mudstone member, Onnagawa formation ; IGPS coll. cat. no. 76605 (pl. 7, fig. 5), apical axis 37.5μ, transapical axis 25μ, from IGPS loc. no. Ak-61, Shinzan diatomaceous mudstone member, Onnagawa formation.
Remarks : Reinhold (*l. c.*) proposed the variety for specimens having a broader marginal zone than the species. The form found in the present samples is identified with the variety by the broad submarginal zone, but has its inner-margin less obviously defined than that shown on Reinhold's original figures.

Marginal pseudo-nodule is small and obscure, placed on the inner edge of the submarginal zone ; marginal spinules are placed at the inner edge of valve margin. *Previous records of occurrences* : Reinhold wrote that the variety was found in the *Globigerina*-marl of the Megeri formation (Upper Miocene, according to Reinhold), and particularly found very frequent in the Megeri foımation lower zone, where it serves as a good marker for correlation.
Occurrences in the present material (Chart 6) : The variety was found very rare to rare in seven samples of the Onnagawa formation, and was also found present in the sample of the higher horizon, Ao-28 of the Matazawa formation. Since the occurrences are neither consistent nor particular at a certain horizon, the variety is of little value inthe present analysis.

Actinocyclus ingeus Rattray

Pl. 7, figs. 6–9; Pl. 8, figs. 1–4.

Actinocyclus ingens RATTRAY, 1890, Quekett Micros. Club., Jour., 2d ser., vol. 4, p. 149, pl. 11, fig. 7. - DE TONI, 1894, Sylloge algarum, p. 1167.

Size range of measured specimens : 35–85μ in diameter.
Figured specimens : IGPS coll. cat. no. 76606 (pl. 7, figs. 6a, 6b), 58μ in diameter, from IGPS loc. no. Ao–12, Owasawa formation; IGPS coll. cat. no. 76607 (pl. 7, fig. 7), 44.4μ in diameter, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76608 (pl. 7, figs. 8a, 8b), 60μ in diameter, from IGPS loc, no. Ao–9, Owasawa formation; IGPS coll. cat. no. 76609 (pl. 7, fig. 9), 64μ in diameter, from IGPS loc. no. Ao–12, Owasawa formation; IGPS coll. cat. no. 76610 (pl. 8, fig. 1), 53μ in diameter, from IGPS loc. no. Ao–12, Owasawa formation; IGPS coll. cat. no. 76611 (pl. 8, fig. 2), 50.5μ in diameter, from IGPS loc. no. Ao–12, Owasawa formation; IGPS coll. cat. no. 76612 (pl. 8, fig. 3), 40μ in diameter, IGPS loc. no. Ao–9, Owasawa formation; and IGPS coll. cat. no. 76613 (pl. 8, figs. 4a, 4b), 40μ, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation.
Remarks : An important character which distinguishes *A. ingens* from such diatoms of similar areolation as *A. Ehrenbergii* var. *Ralfsii*, and var. *crassa* is the structure of the pseudonodule. The pseudonodule of this species is that what Rattray (*l.c.*) classified as indefinite, being not sharply circum scribed, but surrounded by several delicate little poroids, instead of a sharply manifested hyaline ring as of the varieties of *Actinocyclus Ehrenbergii*. Rattray proposed *Actinocyclus ingens* for such *Actinocyclus* which has concentrically undulated valve, rising gradually from center to about 2/3 of radius and then slopes down outwardly; with radially arranged areolae, round to subangular, shorter ones

of which leaves subulate interstitial hyaline areas at their inner ends; and has a submarginal zone made by oblique decussating rows of finer areolae well developed. Areolae on the valve surface, according to Rattray, are 6, 4, 6, and 9 in 10μ, changing their size from center to the submarginal zone through the highest zone, where the areolae are largest.

He gave a detailed description for the shape of areola, but since it varies with the focus, the present writer only cites the characters which, he believes, are diagnostic to the species.

In the samples studied, there are found many specimens referable to *Actinocyclus ingens*. However, practically no two specimens look alike, showing a chain of transition from one extreme to another. Specimens shown in pl. 7, fig. 9 and pl. 7, figs. 8a, 8b exactly match Rattray's description and figures; one in pl. 7, figs. 6a, 6b is an extreme having a wider submarginal zone; whereas, the one in pl. 8, fig. 1 serves as an example of specimens bearing a narrower submarginal zone.

With the submarginal zone becoming narrower, the valve surface tends to be flatter, as are shown by pl. 8, figs. 2, 3, and by pl. 8, figs. 4a, 4b. On these specimens, the submarginal zone in the sense of Rattray's description does not exist, and they would safely be identified with *Coscinodiscus elegans* Greville, if the pseudonodule is lacking. As mentioned previously, the pseudonodule of the species is sometimes very hard to observe, and easily overlooked by a casual observation. In some cases, its presence is easier to notice by lower magnification, (10$\times$20), rather than by higher ones (40$\times$20 and higher).

All *Actinocyclus ingens* figured here were confirmed to have a pseudonodule crossing the submarginal zone, although not all figures show it properly.

Remarks: Upon proposing this species, Rattray (*op. cit*). gave the following localities as for the new species, namely; "Brünn Tegel, Moravia (Griffin), Santa Monica (Kinker), Los Angels (Deby), Monterey (Hardman)". Although the exact localities and geologic ages are unknown, the last three localities are most probably of the Miocene in California. The present writer confirmed the occurrence of this species in samples collected at the type locality of the Monterey formation, the Delmontian in age (for the locality, see Hanna, 1928, and Kanaya, 1957, p. 53).

The species has no previous record in Japanese Tertiary deposits. However, it is highly probable that the species had been identified with *Coscinodiscus elegans*, or *Actinocyclus Ehrenbergii* and its varieties in the previous works.

Occurrences in the present material (Chart 6): Though in various frequencies, the species was found consistent in the diatom assemblage B of the Onnagawa formation. The species was always frequent in the studied samples of the Yorinobezawa, and Owasawa formations. Despite that the species was found present also at the samples of the higher horizons, the way it occurs in the diatom assemblages of the Onnagawa formation is such that makes the species one of the marker of the assemblage B (*Coscinodiscus Yabei* assemblage). See also Chart 7.

Actinocyclus tsugaruensis Kanaya, n. sp.

Pl. 8, figs. 5–8.

Description: Valve circular, broadly concave or convex in inner half of radius, 45–80μ in diameter. Areolae radially arranged, quadrate to polygonal, and their distinct chamber-walls form a complete meshwork over the valve surface. Chamber openings round and distinct. The areolea increase their size from center (5–6 in 10μ) to 2/3 of radius (4–5 in 10μ), from where they gradually decrease their size (5–6 in 10μ) outwardly until the submarginal zone where the areolae are much smaller (9–12 in 10μ). Margin narrow, radially striated. Submarginal zone is made by a few concentric rows of smaller areolae, and is rarely broad enough to show decussating structure. Pseudonodule conspicuous, circular, surrounded by minute poroids, and is always placed in the submarginal zone. Central space hyaline, indefinite in shape, enclosed by a ring of the innermost areolae of ıadial rows, and with 2–6 subangular areolae. The area is not necessarily present, sometimes being completely occupied by ordinary areolation. Interstitial meshes at the ends of shorter radial rows are very small, if not totally lacking.
Holotype: IGPS coll. cat. no. 76615 (pl. 8, figs. 5a, 5b, 53μ in diameter, from IGPS loc. no. Ao–9, Owasawa formation.
Paratypes: IGPS coll. cat. no. 76614 (pl. 8, figs. 6a, 6b), 53μ in diameter, from IGPS loc. no. Ao–13, Owasawa formation; IGPS coll. cat. no. 76616 (pl. 8, figs. 7a, 7b), 75μ in diameter, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76617 (pl. 8, fig. 8), 59.3μ in diameter, from IGPS loc. no. Ao–9, Owasawa formation.
Remarks: Through investigating variations of *Actinocyclus ingens*, the writer found a group of diatoms which can not be included under *Actinocyclus ingens*. The new species is easily distinguished from the typical *Actinocyclus ingens* by its quadrate to hexagonal areolae, forming a closed meshwork by their narrow but distinct chamber walls. However, the presence of specimens with subulate interstitial meshes (pl. 8, fig. 8) as of *Actinocyclus ingens* suggests that the new species is transitional from *A. ingens* through such individuals. No illustration referable to the new species has ever been given in the diatom literatures of Japan.
Occurrences in the present material (Chart 6): The species tends to occur more often in the diatom assemblages A, and B, than that of C of the Onnagawa formation. With one exception, it also occurred in various frequencies in all samples

from the Yorinobezawa and Owasawa formations. Although the species was also found present in the sample of the higher horizon, Ao–27 of the Matazawa formation, it serves as one of the eight marker species whose joint occurrences define the assemblages B (*Coscinodiscus Yabei* assemblage). See also Chart 7.

Faily Saleniaceae Schütt, 1896
[as Solenioideae; emend. Karsten, 1928]
Subfamily Solenioideae Schütt, 1896
[as Solenieae; emend. Karsten, 1928]
Tribe Rhizosolenieae Schütt, 1896
[as Rhisosoleniinae; emend. Karsten, 1928]

Genus ***Rhizosolenia*** (Ehrenberg) Brightwell, 1858

Rhizosolenia spp.
Pl. 9, figs. 1-4.

Figured specimens: IGPS coll. cat. no. 76689 (pl. 9, fig. 1), broken specimens, length 61.5μ, from IGPS loc. no. Ak-67, Shinzan diatomaceous mudstone member, Onnagawa formation ; IGPS coll. cat. no. 76690 (pl. 9, fig. 2), a broken specimen, 48μ in length, from IGPS loc. no. Ak-53, Shinzan diatomaceous mudstone member, Onnagawa formation ; IGPS coll. cat. no. 76691 (pl. 9, fig, 3), a broken specimen, 114μ in length, from IGPS loc. no.Ak-54, Shinzan diatomaceous mudstone member, Onnagawa formation ; IGPS coll. cat. no. 76692 (pl. 9, fig. 4), a broken specimen, 69μ in length, from IGPS loc. no. Ao-12, Owasawa formation.

Remarks: In classifying the genus *Rhizosolenia*, the writer follows Hustedt (1929, p. 568), and Cupp (1943, p. 79) who applied Karsten's scheme, which places more emphasis on the symmetry of the cell than on the nature of the intercalary bands.

In the samples studied, at least four forms illustrated were recognized. They have symmetrical valves, and a straight and centrically based apical process with a canal through it. The symmetrical valve and the centrically based process prove that they belong to the *Simplices* (of Karsten: simpliceszellen symmetrisch, Stachelspitzs der Shale in jede Lage median), but specific identification is not warranted, inasmuch as only the upper portion of calyptrae was found preserved in the samples studied.

According to Karsten (1928, p. 233), 34 *Rhizosolenia* species had been then described, all marine plankton, with a few exceptions. Hustedt (1929. pp. 564-609) treated 21 species of the European waters, including two fresh- and one brackish-water species of his *Longisetae*. In addition, Huber-Pestalozzi (1942, p. 418) reported two fresh-water and one "Salzwasser" species from Norway and Africa, both of which belong to *Longisetae*.

Judging from the fact that all species belonging to *Simplices* occur exclusively in marine waters, it is assumed that *Rhizosolenia* in the present samples are of marine forms, even though their specific identification were not made.

Occurrences in the present material (Chart 6) : The counting should have been made for each form to discuss their stratigraphic value.

Family Biddulphiaceae Schütt, 1896

[as Biddulphioideae ; emend. Karsten, 1928]

Subfamily Biddulphioideae Schütt, 1896

[as Biddulphieae ; emend. Karsten, 1928]

Tribe Triceratieae Schütt, 1896

[as Triceratiinea ; emend. Karsten, 1928]

Genus ***Triceratium*** Ehrenberg, 1841

Triceratium sp. α

Pl. 9, fig. 5.

Figured specimen : IGPS coll. cat. no. 76716 (pl. 9, fig. 5), 52. 5μ in length of side, from IGPS loc. no. Ak-61, Shinzan diatomaceous mudstone member, Onnagawa formation.

Size range of measured specimens : 40-55μ in length of side.

Remarks : Valve trigonal in valve view, depressed in center ; sides slightly concave with round angles which only weakly elevate. Areolae radially arranged, equal in size, 4.5 in 10μ, except at angles where they are much smaller. Areolae are resolved into complete meshwork in higher magnification (higher than 100×10), otherwise they are punctated and round.

The present form shows the closest resemblance to Schmidt's figure (1876, pl. 76, fig. 29) from Japan. Grunow was in the opinion of naming the figure as *Triceratium arcticum* Brightwell var. *japonica minor* (Schmidt, *l. c.*). The variety was not accepted by neither De Toni (1894, p. 920), nor by Hustedt (1930, p. 816) when they treated the species.

With the depressed center, the present form could be placed under *Triceratium formosum* Brightwell (Hustedt, 1930). From another similar species, *Triceratium repletum*, it is distinguished by coarser areolae, observed to form a meshwork in

higher magnification. Further taxonomical discussion is reserved, since Brightwell's monograph (1856), has not been accessible to the writer.
Occurrences in the present material (Chart 6) : In the samples from the Onnagawa formation, the species occurred in samples containing the assemblage B (*Coscinodiscus Yabei* assemblage). It was also found present in a sample from the Yorinobezawa formation. Occurrences are too rare to make the species as a marker of the assemblage.

Triceratium sp. ß

Pl. 9, figs. 6, 7.

Figured specimens : IGPS coll. cat. no. 76717 (pl. 9, fig. 6), 19.7μ in the length of a side ; IGPS coll. cat. no. 76718 (pl. 9, fig. 7), 24μ in the length of a side, both from IGPS loc. no. Ak-55, Shinzan diatomaceous mudstone member, Onnagawa formation.
Size range of measured specimens : 18-35μ in the length of a side.
Remarks : Valve trigonal, surface fairly flat; sides straight or slightly concave; angles round, flat. Areolae round, observed isolated from each other even in higher magnification (100×15), rather sparse in center, become dense along the side where they are 10 in 10μ ; areolae are not particularly smaller at angles. Areolae tend to be radially arranged, but on some specimens parallel rows along the sides predominate over the radial ones.

This is another small *Triceratium* the writer failed to identify with any known species. Its round, punctated areolae, small valve, and flat angles, seems to suggest its belonging in *Triceratium reticulum* Ehrenberg (Hustedt, 1930, p. 824, figs. 485, 486), but the areolae showing no abrupt size change at angles does not warrant this comparison.
Occurrences in the present material (Chart 6) : The species was very rare in two samples, both contain the diatom assemblage B (*Coscinodiscus Yabei* assemblage) of the Onnagawa formation. The occurrences are too rare to make the species as a marker of the assemblage.

Family Rutilariaceae Schütt, 1896
[as Rutilarioideae, emend. Karsten, 1928]

Subfamily Rutilarioideae
[as Rutilarieae; emend. Karsten, 1928]

Genus ***Rutilaria*** Greville, 1863

Rutilaria epsilon Greville

Pl. 9, fig. 19.

Rutilaria epsilon GREVILLE, 1863, Quart. Jour. Micr. Sci., n. ser. vol. 3, p. 228, pl. 9, fig. 1. Locality : "Monterey deposit". - DE TONI, 1894, Sylloge algarum, p. 1021.

Figured specimen : IGPS coll. cat. no.76696 (pl. 9, fig. 19), partly broken 77.5μ in length, assumed apical length c.a. 120, from diatom loc. 5, Owasawa formation,

Remarks : The presence of a hyaline, punctum free area surrounding the central marking is the basis of the present identification. In this respect, at least two of the excellent illustrations given by Schmidt (1893, pl. 183, figs. 13-16) as of *Rutilaria epsilon* Grev. var. *longicornis* Brun and Temp. have a hyaline area surrounding the central marking, and thus *Rutilaria epsilon* of Greville's sense ; whereas they are longer than the original figure (Greville, *l. c.*, 80μ in length) of the species, and fit better to *R. longicornis* Brun and Temp., so far as the length of valve is concerned. The two figures are fig. 14, and fig. 15, from "Sendai" and "S. Monica", respectively. The specimens here illustrated is identical with the one from "S. Monica", California.

Previous records of occurrences : The type material appears to have been collected from the so-called Monterey formation, California, but no further information is available. Schmidt's figures mentioned indicate the presence of this species in the "S. Monica" and "Sendai" materials, the exact localities, and geologic ages of which are still unknown, though most probably of Miocene. The record of this species from the "Oamaru" deposit, upper Eocene of New Zealand was excluded by De Toni (*l.c.*)

Occurrences in the present material (Chart 6) : As is indicated on Chart 6, the species was found present in three samples of the present material, one from the Onnagawa, one from the Yorinobezawa, and one from the uppermost portion of the Owasawa formation.

Order Pennales Schütt, 1896

[as Pennatae; emend. Karsten, 1928]

Suborder Araphideae Hustedt, 1927

Family Fragilariaceae Schütt, 1896

[as Fragilarioideae; emend. Karsten, 1928]

Subfamily Tabellarioideae Schütt. 1896

[as Tabellarieae; emend. Karsten, 1928]

Tribe Tabellarieae Schütt, 1896

[as Tabellariinae; emend. Karsten, 1928]

Genus ***Grammatophora*** Ehrenberg, 1841

Grammatophora spp.

Pl. 9, figs. 8–10.

At least three forms were distinguished among the *Grammatophora* valves in the samples studied. Specific identification was, however, not successful, since none of the specimens has the surface markings resolved by the optical microscopic observation. It occurred to the writer that the specimens at hand were all intercalary bands; but double-lined margin, and flat nature of the specimens seemed to exclude this possibility.

Two forms are here illustrated; in their outline, one (pl. 9, fig. 8) has a close resemblance to Pantocsek's figure of *Grammatophora stricta* Ehr. var. *fossilis* Pantocsek (Pantocsek, 1886, Teil 1, pl. 26, fig. 239b from Dolje), and the other (pl. 9, figs. 9, 10) to *Grammatophora stricta* Ehr. var. *biharensis* Pantocsek (*ibid.* pl. 30, figs. 307, from Elesd). According to Pantocsek, "Doje" locality, Kroat, is "Sarmatischen Stufe, oberste Miozän", and "Elesd" locality, Hungary is "Pontische Stufe, untereste Pliozän"; and they were so cited by Pia (1927, in Hirmer, p. 46). *Figured specimens* : IGPS coll. cat. no. 76679 (pl. 9, fig. 8), 52.5μ in apical length ; IGPS coll. cat. no. 76680 (pl. 9, fig. 9), 84μ in apical length ; both from IGPS loc. no. Ao–13, Owasawa formation; and IGPS coll. cat. no. 76681 (pl. 9, fig. 10), 137μ in apical length, from IGPS loc. no. Ao–12, Owasawa formation.
Occurrences in the present material (Chart 6) : The genus tends to occur more often in the samples from the upper horizons, than those from the Onnagawa and its correlative formations.

Subfamily Fragilarioideae Schuütt 1896

[as Fragilarieae; emend. Karsten, 1928]

Tribe Fragilarieae Schütt, 1896

[as Fragilariinae; emend. Karsten, 1928]

Genus ***Fragilaria*** Lingbye, 1819

Fragilaria hirosakiensis Kanaya, n. sp.

Pl. 9, figs. 11–15.

Description : Valve lanceolate with round ends weakly capitated. Marginal striae short, peripheral, 10–12 in 10μ. The length of apical axis ranges between 20–80μ; transapical axis 4–7μ. Valve outline extremely variable: in shorter specimens it becomes almost elongate quadrate inflated at the middle, while in longer specimens it is narrow lanceolate to linear with weakly inflated middle. In higher magnification (100×20, oil immersion), horseshoe form depressions between marginal striae are recognized.

Holotype: IGPS coll. cat. no. 76674 (pl. 9, figs. 11a, 11b), apical axis 38μ, transapical axis 6μ; striae 10 in 10μ, from IGPS loc. no. Ao–9, Owasawa formation.

Paratypes: IGPS coll. cat. no. 76675 (pl. 9, fig. 13), apical axis 32μ, transapical axis 4.7μ; IGPS coll. cat. no. 76676 (pl. 9, fig. 12), apical axis 48μ, transapical axis 7μ; IGPS coll. cat. no. 76677 (pl. 9, fig. 14), apical axis 29μ, transapical axis 6.5μ; IGPS coll. cat. no. 76678 (pl. 9, figs. 15a, 15b), apical axis 20μ, transapical axis 6.5μ, all from IGPS loc. no. Ao–9, Owasawa formation.

Remarks: Should the Cleve-Euler's key to *Fragilaria* (*Eufragilaria*) A. Cleve (Cleve-Euler, 1953, p. 29) is applied, the new species falls into the category of *Fragilaria bituminosa* Pantocsek: *Fragilaria* with short marginal striae, and with valves "grosser, gestreckt linear".

Pantocsek's species was represented by five varieties, (Pantocsek, 1886, Teil 2, p. 65), all from Hungarian fossil material of fresh-brackish water ? origin, among which to var. *perlonga* (*l. c.*, pl. 10, fig. 171) the present species relates most closely.

Cleve-Euler (1941, p. 184, pl. 10, fig. 203a, b) reported this variety from the samples of Schwedish Lappland ("Alttertiär, marine"), and mentioned that the valve margin, in higher magnification (×2400), bears "Opephora" looks in having "submarginal Poren" between striae. Her figure is longer than Pantocsek's original, and the middle of the valve is slightly inflated, instead of the straight look of the Pantocsek's figure. Some of the present specimens are almost identical in appearance with Cleve-Euler's figure. Marginal structure is, however, slightly different: the markings between the striae are not pores, but rather horseshoe form depressions.

Some of the present specimens resemble in outline *Synedra tabulata* var. *obtusa* (Arenott)(Cleve-Euler, 1953, fig. 392d) to which Cleve-Euler designated two Van Heurck's figures (Van Heurck, 1881, pl, 41, figs. 12, 19). However, the striae described for the variety is finer, 14–16 in 10μ, than that observed on the present specimens.

Placing the new species under the Genus *Fragilaria* is not certain. It is so placed because in several occasions two frustules were found united in broad girdle view suggesting that they might have been in a band-chain.

Such a girdle view, however, was once illustrated by Van Heurck for his *Synedra affinis* var. *hydrida* forma *breviores* (Van Heurck, 1884, pl. 14, fig. 10).

Occurrences in the present material (Chart 6) : The species occurred, in variable frequencies, in all samples examined but in only two from the Shinzan diatomaceous mudstone member, Onnagawa formation. In several samples, the species was found very abundant to dominant, constituting, in number, the main body of the assemblages. Because the species occurred so ubiquitously, and because its outbreaks are so sporadical with regards to the stratigraphic po sitions, the species was found useless so far as at the analysis of the present material (see also Chart 7).

Genus ***Thalassiothrix*** Cleve and Grunow, 1880

Thalassiothrix longissima Cleve and Grunow

Pl. 9, fig. 20.

Synedra thalassiothrix CLEVE, 1873, K. Svenska Vet. -Akad. Handl., Bihang, Bd. 1, no. 13, p. 22, pl. 4, fig. 24 (inaccessible).

Thalassiothrix longissima CLEVE and GRUNOW, 1880, K. Svenska Vet. - Akad. Handl., Bd. 17, no. 2, p. 108 (inaccessible). - HUSTEDT, 1932, Kieselalgen, Teil 2, p. 247, fig. 726. - LOHMAN, 1941, U.S. Geol. Survey Prof. Paper 196-B, p. 82, pl. 17, fig. 5.

Size range of the measured specimens : Width 3.5–5μ; the longest fragment 130μ in length.

Figured specimen : IGPS coll. cat. no. 76715 (pl. 9, fig. 20), 130μ in length, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks : Thread like fragments in variable length found in the present material are included under *Thalassiothrix longissima*. Although the presence of long fragments, being as long as 130μ, warrants this identification, it does not exclude the possibility of misnaming other species of *Thalassiothrix* appearing in fragments without ends. No complete specimen of this long species, known to attain as long as 4000μ in length, was met with during the present observation.

Previous records of occurrences : Lohman has stated that the species occurs commonly to frequent in middle Miocene and later rocks in California (Lohman, *l.c.*).

As Lohman mentioned, Brun and Tempère (1889, p. 74) recorded that the species (and *Th. Frauenfeldii* var. *Javanica*) were found in considerable abundance in their "Calcaire de Yédo et de Sendai", but the locality and geologic age of the sample are unknown.

As it does in the present material, the species occurs ubiquitously in the Japanese marine diatomaceous rocks younger than medial Miocene in age.

Lohman stated that the species is living as "..... a true pelagic marine cold-water diatom and is very common in the Arctic seas, the North Atlantic, along the European coasts, and in the South Atlantic and South Pacific." (Lohman, *l.c.*).

In bottom sediments, *Th. longissima* was found to be a qualitatively dominant species in the Sea of Okhotsk (Jousé, 1957, p. 185); while it was also found widespread, sometimes in high frequency, in many levels of deep-sea cores raised from the equatorial Pacific, Atlantic, and Indian Oceans (Kolbe, 1954, p. 46; 1956;, p. 179; 1957, p. 44, respectively).

Occurrences in the present material (Chart 6) : Since the species always occurred in fragment state, the counting is not expected to have been accurate. Occurring in most of the samples examined with variable frequencies, the species does not seem to have stratigraphic value.

Suborder Monoraphideae Hustedt, 1927

Family Achnanthaceae Schütt, 1896

[as Achnanthoideae; emend. Karsten, 1928]

Subfamily Cocconeidoideae Schütt

[as Cocconeideae; emend. Karsten, 1928]

Genus ***Cocconeis*** Ehrenberg, 1838

Cocconeis antiqua Tempère et Brun

Pl. 10, figs. 1, 2.

Cocconeis antiqua Tempére et Brun, Brun and Tempere, 1889, Soc. Phys. et d'Hist. Natur., Genève, Mém., tome 30, no. 9, p. 32, pl. 8, fig. 5. Locality : "Calcarie de Sendai et de Yédo". - Schmidt, 1894, Atlas der Diatomaceenkunde, pl. 191, figs. 49, 52 ; also figs. 50, 51.

Size range of measured specimens : 30–70.5μ in apical axis.

Figured specimens : IGPS coll. cat. no. 76626 (pl. 10, fig. 1), apical axis 70.5μ, transapical axis 50μ, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76627 (pl. 10, fig. 2) 37.5μ in apical axis, 26.4μ in transapical axis, from IGPS loc. no. Ao–13, Owasawa formation.

Remarks : Only raphe-free valves were available. An illustrated specimen (pl. 10, fig. 1) represents the larger specimens found in the samples studied : transapical straiae 8 in 10μ, poroids 6–7 in 10μ,

In the larger specimens, the axial area transapically inflates at center ("pseudo-stauroid") as orginally described. The axial area, however, becomes narrower to narrow lanceolate or even to almost linear in smaller specimens (e.g. pl. 10, fig. 2), which are, ranging between 30–40μ in apical axis, much smaller than what Brun and Tempère described (60–70μ) for the species. More extensive examination of this group of diatoms may result in proposing a variety for the smaller specimens.

C. antiqua var. *fossilis* Cleve which, according to Cleve, ranges between 50–85μ in apical axis, has lanceolate axial area, instead of pseduo-stauroid of the species. (Cleve, 1895, p. 177, Cleve took Schmidt's pl. 191, figs. 44–46 as lectotypes).

Previous records of occurrences: Geologic age and localties of the type material (*l. c.*) and of Schmidt's figures (*l. c.*, pl. 191, figs. 49, 52), remarked as of Sendai (Brun) and Hokkaido (Kinker), respecitvely, are unknown.

Occurrences in the present material (Chart 6): In the diatom assemblages of the Onnagawa formation, the occurrence of this species became fairly consistent in the assemblage C, whereas it was absent in the samples containing the lower assemblages except sample Ak–63 of the assemblage B (see Chart 7). The species was found present in sample Ak–70–5 from Yorinobezawa formation, and sample Ao–13 from the uppermost portion of the Owasawa formation, as well as those from the higher horizon, the Maido formation.

Cocconeis curvirotunda Tempère et Brun

Pl. 10, fig. 3.

Cocconeis curvirotunda TEMPÉRE et BRUN, BRUN and TEMPÉRE, 1889, Soc. Phys. et d'Hist. Natur., Genève, Mém., tome 30, no. 9, p. 32, pl. 8, fig. 6. Locality: "Calcaire de Sendai et de Yédo". - SCHMIDT, 1896, Atlas der Diatomaceenkunde, pl. 195, figs. 12–16.

Cocconeis notabilis PANTOCSEK, 1893, Foss. Bacill. Ungarns, Teil 3, pl. 35, fig. 492. Locality: "Wembets".

Figured specimen: IGPS coll. cat. no. 76628 (pl. 10, fig. 3), apical axis 94+μ, transapical axis 69μ, partly broken from IGPS loc. no. Ak–64, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks: Only raphe-free valves were found in the samples studied. The width of zone of marginal rows relative to the transapical length of valve, varies in specimens. The number of longitudinal parallel rows of short striae also varies from 4–6.

Under the present name, raphe-free valves of *Cocconeis circumcincta* Schmidt may have been also included here since, as was shown by Schmidt's figure (Schmidt, 1896, pl. 195, fig. 7), the two species are only distinguishable by comparing the valves with raphe.

Previous records of occurrences: Exact locality and geologic age of "Calcaire de Sendai et de Yédo" (Brun and Tempère, *l.c.*) has not so far been ascertained. Schmidt's figures are also from "Sendai" sample which lacks further information.

Jousé recorded that the species was found at one station in the bottom surface sediments of the Sea of Okhotsk (Jousé, 1957, p. 186).

A synonym, *Cocconeis notabilis* Pantocsek (*l.c.*), was described from "Wembets", Japan. "Wembets" is read "Enbetsu" in Japanese, and the occurrence was from the lower Pliocene Enbetsu formation, Hokkaido, Japan (Okuno 1952, p. 3).
Occurrences in the present material (Chart 6) : So far as the writer observed, the species was restricted, in the Onnagawa formation, to theassem blage C (Chart 7). The species was also found present in Ao–11, of the Owasawa formation, as well as in the samples from the higher horizons.

Cocconeis formosa Brun

Pl. 10, figs. 4, 5.

Cocconeis formosa BRUN, 1891, Soc. Phys. et d'Hist. Natur., Genève, Mém. tome 31, p. 16, pl. 18, fig. 6 (inaccessible). - SCHMIDT, 1894, Atlas der Diatomaceenkunde, pl. 193, figs. 42-47. - PANTOSCEK, 1893, Foss. Bacill. Ungaruns, Teil 3, pl. 32, fig. 457. - CLEVE, 1895, Kongl. Svenska Vet. Akad., Handl. Bd. 27, no. 3, p. 181.

Size range of measured specimens : 25–95μ in length of apical axis.
Figured specimens : IGPS coll. cat. no. 76629 (pl. 10, figs. 4a, 4b), apcial axis 92μ, transapical axis 73μ, from IGPS loc. no. Ak–59, Shinzan diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76630 (pl. 10, fig. 5), apical axis 30.8μ, transapical axis 18.2μ, from IGPS loc. no. Ak–65, Shinzan diatomaceous mudstone member, Onnagawa formation.
Remarks : The raphe-free valves of this species are characterized by slightly radiate strong transapical ribs anastomosing into a network of subrectangular areoleae, 4 in 10μ. Axial area narrow lanceolate, and stauroid at center.

Among Schmidt's figures (*l.c.*) of the species, fig. 46 bears the closest resemblance to the specimens found in the present samples. The transapical extension of the stauroid hyaline area is a subject of variation : it reaches to the valve margin on some specimens (pl. 10, fig. 5), whereas in some cases it tapers outwardly and terminates before reaching the margin (pl. 10, figs. 6a, 6b).

The raphe-free valve of *C. formosa* resembles that of *C. scutellum* Ehr., from which it differs by longitudinal ribs being irregular and obscure if not totally lacking, by lacking marginal structure of fine areolae, and by broader axial area, stauroid at valve center.
Previous records of occurrences : All of Schmidt's figures are of Japanese specimens. He remarked that specimens of figs. 15, 42 and 45 were from "Hokkaido (Kinker)"; figs. 43, 44 and 46 were from "Sendai (Brun)"; and fig. 47 was from "Sendai (Jordan)". The so-called "Sendai" material is of fossil. However, as it is men-

tioned everywhere in the present paper, no further information which might help assuming their exact localities and geologic ages are available.

The Pantocsek's record (*op. cit.*) was from "Wembets", which, according to Okuno (1952, p. 3), should be "Enbetsu" of the Enbetsu formation, the lower Pliocene in age.

Occurrences in the present material (Chart 6) : As it was the case of *Cocconeis antiqua*, the species has become a fairly consistent element in the diatom assemblage C of the Onnagawa formation. The samples of the other areas were barren of this species (see Chart 7).

Cocconeis vitrea Brun

Pl. 10, fig. 6.

Cocconeis vitrea BRUN, 1891, Soc. Phys. et d'Hist. Natur., Genève, Mém., tome 31, p. 19, pl. 18, fig. 2 (inaccessible). - SCHMIDT, 1894, Atlas der diatomaceenkunde, pl. 194, fig. 11 (unnamed).

Figured specimen : IGPS coll. cat. no. 76631, (pl. 10, figs. 6a, 6b), apical axis 62.5μ, transapical axis 50μ, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks : Except that the transapical and marginal ribs are coarser (8–9 in 10μ), the present form is identical with Schmidt's figure (pl. 194, fig. 11) which, according to Schmidt, was referred by Brun, the original author, to *Cocconeis vitrea*.

Later, Fricke (1902) assigned figures 8, 10 and 11 of Schmidt (*op. cit.* pl. 194) to *Cocconeis vitrea*. Since the original description of the species is not accessible to the present writer, he cannot decide whether the figures 8 and 10, added by Fricke to show valves with raphe, are of *Cocconeis vitrea*, and the present identification is made strictly with figure 11 only.

Previous records of occurrences : The Schmidt's figure was from "Santa Monica", the locality and geologic age of the material is undeterminable (Hanna, 1936, p. 109). Most probably of Miocene in age. Jousé (1957, p. 186) recorded the species in the bottom surface sediments of the Sea of Okhotsk at five stations.

Occurrences in the present material (Chart 6) : The species was found only in sample Ak–63 which contains the diatom assemblage C of the Onnagawa formation (Chart 7).

Suborder Biraphideae Hustedt, 1927

Family Naviculaceae Schütt, 1896

[as Naviculoideae; emend. Karsten, 1928]

Subfamily Naviculoideae Schütt, 1896

[as Naviculeae; emend. Karsten, 1928]

Genus ***Rouxia*** Brun and Heribaud, 1893

Rouxia Peragelli Brun and Heribaud emend. Hanna

Pl. 9, figs. 16–18.

Rouxia Peragalli BRUN and HERIBAUD, in HERIBAUD, 1893, Diat. d'Auvergen, p. 156, pl. 1, fig. 12a, not b and c. Locality : "Japan. Fossil : Deposit at Abokiri and in limestone at Sendai" (cited frlom Hanna, 1930a, p. 181). - BRUN, 1893, Le Diatomiste, vol. 1, p. 177, pl. 24, fig. 2. - HANNA, 1930, Jour. Paleont., vol. 4, no. 2, p. 180, pl. 14, figs. 1, 5 (with figures reproduced form Heribaud, *1. c.*, and Brun 1. *c.*).

Figured specimens : IGPS coll. cat. no. 76693 (pl. 9, figs. 16a, 16b), apical length 40μ, transapical length 8μ; IGPS coll. cat. no. 76694 (pl. 9, figs. 17a, 17b), apical length 42μ, transapical length 8.1μ; IGPS coll. cat. no. 76695 (pl. 9, figs. 18a, 18b), partly broken, apical length 46μ, transapical length 8.3μ, all from IGPS locll. no. Ak–55, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks : Upon reviewing the genus *Rouxia*, Hanna (1930, *op. cit.*, pp. 179–188) reproduced the original descriptions and figures of the previously described species of the genus to that date. He confined *Rouxia Peragalli* to flat and ovate form; and for the form with the sigmoid girdle view and angular outline, a new species *Rouxia yabei* was proposed, taking two of Heribaud's figures (1983, *op. cit.*, fig. 12b, c) as types. The present specimens are identified with *Rouxia Peragalli* emended by Hanna.

All specimens passed under the writer's observation were flat, but not all of them are ovate : some valves are elongate ovate with both sides almost parallel, but not as long as of *Rouxia californica* in the samples of the Onnagawa and its correlative formations.

Previous records of occurrences : The species has not been reported elsewhere than in type materials mentioned in Heribaud's paper. Brun mentioned no locality. The locality and geologic age of "Abokiri" and "Calcaire de Sendai" materials still remain unknown.

Occurrences in the present material (Chart 6) : The species was found in 12 samples out of 26 from the Onnagawa formation. The differences in frequencies between the three assemblages do not seem to be significant. The species was also found in one of the Yorinobezawa, and two of the Owasawa formation samples. The rather high frequencies in samples of the Matazawa formation, a higher horizon than that of the Onnagawa and its correlative formations, is noteworthy. The high frequency, 39 specimens in a single count of 200 specimens, in sample Ao–28, howevei, includes tentatively specimens which may have better been identified with *Rouxia californica* besides the true *Rouxia Peragalli*.

Nevertheless, the present observation confirms that *Rouxia Peragalli* which has so far been reported only from the type material of an unknown Japanese locality, distributes in this portion of Miocene rocks of Japan, and appeared in a horizon, stratigraphically lower than that of *Rouxia californica* which, according to Hanna (1930a, p. 186) is excessively abundant at a horizon about 500 feet below the exposed top of the diatomite at Lompoc quarry, California. The portion is the Delmontian in age according to Bramlette (1946, pl. 2, column 8).

Family Epithemiaceae Hustedt, 1927
[as Epithemioideae; emend. Karsten, 1928]
Subfamily Epithemioideae Karsten, 1928
Genus ***Denticula*** Kützing, 1844

Denticula lauta Bailey

Pl. 10, figs. 7–16.

Denticula lauta BAILEY, 1854, Smithonia Contr. Knowl., vol. 7, p. 9, figs. 1, 2. VAN HEURCK, 1881, Syn. diat. Belgique, pl. 49, figs. 1, 2. - WOLLE, 1890, Diat. N. America, pl. 46, fig. 10; pl. 56, figs. 16, 17. - HANNA, 1932, California Acad. Sci., Proc. 4th ser., vol. 20, no. 6, p. 188, pl. 11, fig. 1.

Eunotia sancti antonii EHRÉNBERG, 1854, mikrogeologie, pl. 33, XII, figs. 9, 10. Not: pl. 34 V B, fig. 7 from "St. Antonio, Capverden, Africa."

Diagnostic features: Valve lanceolate to linear lanceolate with obtuse round ends. Intercalary bands with round perforations, 2–3.5 in 10μ along the apical axis. Transapical septa situated on hyaline "Steg" of the intercalary band (primary septa) develop to reach to the valve surface; and ones inserted between the primary septa (secondary septa) do not necessarily reach to the surface, being confined to develop only along the base of the valve mantle. Valve surface is ornamented with transapical lines of minute poroids, 2–3 lines between two septa. No canal raphe is observed on valve surface.

Size range of measured specimens: 11–46μ in length of apical axis; 3.2–7μ in length of transapical axis.

Figured specimens: IGPS coll. cat. no. 76661 (pl. 10, fig. 7, valve view), apical axis 13.7μ, transapical axis 3.2μ; IGPS coll. cat. no. 76662 (pl. 10, fig. 8, girdle view), apical axis 15μ, pervalveraxis 10μ; IGPS coll. cat. no. 76663 (pl. 10, fig. 9, girdle view), apical axis 14μ, pervalver axis 8μ; IGPS coll. cat. no. 76664 (pl. 10, figs. 10a, 10b), apical axis 18.4μ, transapical axis 7.3μ; IGPS coll. cat. no. 76666 (pl. 10, fig. 12, valve view), apical axis 23μ, transapical axis 6μ; IGPS coll. cat.

no. 76665 (pl. 10, fig. 11, girdle view), apical axis 27.5μ, pervalver aixs 9μ; IGPS coll. cat. no. 76667 (pl. 10, fig. 13, girdle view), apical axis 32μ, pervalver axis 8.5μ; IGPS coll. cat. no. 76668 (pl. 10, figs. 14a, 14b, valve view), apical axis 43.4μ, transapical axis 7μ; IGPS coll. cat. no. 76728 (pl. 10, figs. 15a, 15b, girdle view), apical axis 15μ, pervalver axis 7μ; IGPS coll. cat. no. 76733 (pl. 10, fig. 16), apical axis 13.6μ.

Nos. 76661, 76662, 76663, 76668, and 76733 are from IGPS loc. no. Ao–9, Owasawa formation, no. 76664 is from IGPS loc.no. Ao–10, Owasawa formation; nos. 76666, 76665, and 76667 are from IGPS loc. no. Ao–12, Owasawa formation; and no. 76728 is from C.A.S. loc. 1068, east of Sharktooth Hill, Kern County, California, the Round Mt. Silt, Relizian in age.

Remarks: The classic figures of Bailey (*l.c.*) and Ehrenberg (*l.c.*), left much to be discussed.

According to Hanna (*op. cit.*, p. 189), Bailey's and Ehrenberg's collections were obtained from the outcrops around San Francisco Bay, from where Hanna found in abundance diatoms what he considered to be *Denticula lauta*.

Hanna was right in identifying *Denticula lauta* in his Sharktooth Hill materials of the "upper Temblor" (Hanna, *l.c.*), and the present writer found the species also in other samples from California localities of diatomaceous rocks ranging from the Relizian to the Delmontian in age. In three of these samples, *Denticula lauta* was particularly abundant, and measurements of a hundred *Denticula lauta* from each of the three samples[3] were compared with that of the Japanese specimens examined.

Diatoms referable to *Denticula lauta* were measured to have shorter apical axis in California samples than in the Japanese material. In the California samples, about 90 percent of specimens fell within a range of 10–25μ in apical axis; whereas, most of the Japanese specimens are of 20–35μ. The minimum and maximum apical length were 5μ and 35μ, respectively, for the California specimens, and 11μ and 46μ for the Japanese specimens.

Most of Japanese specimens longer than 20μ have secondary transapical

3) White impure diatomite from about 100–125 feet below the bone bed (Hanna. 1932. p. 161), C.A.S. loc. 1068 east side of Sharktooth Hill, California; Round Mt. Silt. Relizian in age (Kanaya, 1957, p. 53); coll. C.C. Church, March, 1956.

Diatomaceous mudstone, from a railroad cutting 300m NW from the gate of Johns-Manville Corp., south of Lompoc, California; upper part of the Upper Monterey Shale of Dibblee (1950), a correlative of the upper member of the Monterey Shale of Woodring and Bramlette (1950), Mohnian in age; coll. T. Kanaya, Aug. 1954.

White diatomite from near the top of the exposure in the quarry of Monterey Products Co., 4 miles east of Del Monte, California, on the Monterey-Salinas Highway (Hanna, 1928. p. 972); Monterey formation, Delmontian in age (Kanaya, 1957, p. 53); coll. T. Kanaya, Nov., 1953.

septa fully developed to reach the valve surface; but on specimens shorter than 20μ, the secondary septa are imperfect and do not reach to the valve surface, being confined to develop along the base of the valve mantle.

On the California specimens, most of which range between 10–25μ in apical length, secondary septa are usually imperfect as are on the Japanese smaller specimens.

The difference in secondary septa giving specimens different appearance in valve view, however, is judged to have nos pecific importance, since a specimen having two types of secondary septa on each valve of a frustule was fortunately found in a Sharktooth Hill sample (pl. 10, figs. 15a, 15b). Van Heurck's figures (*l. c.*) of California specimens, which have 30μ in apical length, are apparently of the form with perfectly developed secondary septa on both valves.

Including this species under the genus *Denticula* leaves considerable doubt. When Kützing (1844) proposed the genus, Genus *Denticula* was that of the Family Fragilarias together with such genera as *Odontidum*, *Fragilaria*, and *Diatoma*, and nothing was mentioned about the keel structure of the genus.

Grunow who noticed the keel structure of diatoms then belonging to the genus placed his *Denticula* in the Family Nitzschieae (Grunow, 1862, p. 546), and included *Denticula lauta* under the genus, but his classification of the genus itself was rather misleading.

Van Heurck (1881), who gave good illustrations of *Denticula lauta* (*l. c.*), placed the genus in his Tribe Fragillariees of the Subfamily Pseudo-Raphidees, under which genus *Epithemia* was then also included.

Hustedt (1927) has been credited to the present application of the Genus *Denticula* as of Epithemiaceae, and the presence of canal raphe on valve surface, inclined from apical axis, has become indispensable for the genus (Karsten, 1928; Hustedt, 1930b),

The present writer failed to find the raphe structure on *Denticula lauta* in both California and Japanese samples. The maximum magnification used was 100×20 oil immersion. Of course, it does not exclude the possibility of finding the canal raphe, probably on the margin, by making use of electron-microscope. Nevertheless, the absence of the raphe structure under the optical microscope distinguishes *Denticula lauta* from the living species of *Denticula* treated by Hustedt (1930b), which all have the canal raphe structure.

It seems to be more than a coincidence that of 19 species listed by Mills (1933–35) as of *Denticula* previously so described, 16 species bearing the canal-raphe have the records of fresh- or brackish-water occurrences. Remaining three, lacking such a structure, do not have the fresh- or brackish-water records.

The three species are: *Denticula lauta*; *Denticula nicobarica* Grunow (Van

Heurck, *op. cit.* pl. 49, fig. 3, from the fossil deposit of Nicobar Island); and *Denticula indica* Grunow (Van Heurck, *op. cit.*, pl. 49, figs. 7, 8, 9, occurrence unknown). California and Japanese diatomaceous rocks yielding *Denticula lauta* are of marine origin, judging from the associated diatom assemblage as well as from other paleontological evidences. The deposit yielding the second species is of marine origin.

The differences in raphe structure as well as in ecological behavior seems to suggest proposing a new genus or a subgenus to include *Denticula lauta*, *Denticula nicobarica*, and possibly *Denticula indica*.

Previous records of occurrences: Hanna (*l.c.*) Round Mt. Silt, Sharktooth Hill, Kern County, California, Relizian (for age, see Kanaya, 1957, p. 53). As it was mentioned, the species occurs in diatomaceous rocks in the Coastal Range of California, ranging from the Relizian to Delmontian. Hanna stated that the abundant occurrences of this species is restricted to a portion of the Miocene higher in the column than the upper part of the "Temblor". The present writer's impression was that the occurrences of the species was affected by local environmental conditions, rather than provincial ones.

Through personal communication, Dr. R. Holmes of the Scripps Institution of Oceanography informed the writer that the diatom closely similar to *Denticula lauta* are commonly found in samples of the Bering Sea, and their occurrences seem to be restricted to waters within a certain temperature and salinity range. Occurrences of the same form in the bottom samples of the areawere also confirmed. This form, and diatoms which have been frequently refer red by Japanese marine biologists as *Denticula* sp. following Akatsuka (1941, p. 78, pl. 17, fig. 12) are probably of the same species.

Mann reported (1907, p. 317) that *Denticula nicobarica* Grunow was found most plentiful in a bottom samples of the Bering Sea. This could be *Denticula lauta*, since the writer found the species in core samples of the same area. Recently, Jousé reported that *Denticula marina* Semina was a qualitatively dominant species in bottom samples of the Sea of Okhotsk (1957, p. 190, pl. 4, figs. 16a, 16b). Her figures suggest that the species may be what the present writer calls *Denticula lauta*.[4]

Critical comparisons of these Recent, Pleistocene, and Tertiary specimens, and further investigation of their geographical distribution, both in bottom and

4) After this manuscript was completed, Dr. A. Jousé kindly sent to the writer a photostat copy of the original description of *Denticula marina* Semina, in which Semina remarked that her new species has a resemblance to *Denticula lauta* Bailey, but because the original description given by Bailey lacks in the diagnose, comparison of two species was impossible.

surface samples of the higher latitudes, will determine the value of this species as a paleoecological indicator.
Occurrences inthe present material (Chart 6): This is the most common species in the present material of the Japanese Miocene, and occurred with high frequencies in all but a few samples from the Onnagawa and its correlative formations; whereas it was rarely met in the samples of the upper horizons. It becomes dominant iu one sample, and abundant in seven samples of the Onnagawa formation (Chart 7), but the fluctuations of frequencies ascertained are such that make the species not dependable to analyse the present material.

***Denticula*? sp.**

Pl. 10, figs. 17–20.

Figured specimens: IGPS coll. cat. no. 76732 (pl. 10, figs, 17a, 17b), apical axis 22.8μ, from IGPS loc. no. Ao–12, Owasawa formation; IGPS coll. cat. no. 76731 (pl. 10, figs. 18a, 18b), apical axis 16μ, IGPS coll. cat. no. 76729 (pl. 10, figs. 19a, 19b), apical axis 16μ, IGPS coll. cat. no. 76730 (pl. 10, figs. 20a, 20b), apical axis 16μ, from IGPS loc. no. Ao–9, Owasawa formation.
Size range of measured specimens: 15–23μ in apical axis.
Remarks: While examining the present material, the writer has met, in a few samples, high frequencies of a small peculiar form which looked like the isolated intercalary bands of *Denticula*. The specimens are elongate-ellipsoidal, hyaline, and have no surface markings. A few pairs of transapical extensions are marginal, and never reach the axial area. They are not the intercalary band of *Denticula lauta*, since the writer observed the latter as to have the transapical "steg" being not interrupted at the middle. A specimen of *Denticula lauta* illustrated in pl. 10, fig. 16 has the valve surface corroded, but it differs from the specimens in question, even if a part of the transapical septum was broken.

The observation that they are not the intercalary band of *Denticula lauta* Bailey is strengthened by that the size distribution of the two forms are different. As was mentioned, the apical length of *Denticula lauta* ranged between 11–46μ, whereas in the same samples the apical length of the form in question fell within a narrow range, mostly around 16μ, and never exceeded 23μ. Furthermore, there seems to be no correlation between the occurrences of *Denticula lauta* and this form.

Whether the form actually represents the intercalary bands of other diatoms is suspected. The transapical extensions are observed to rise as if to hook on to the convex valve surface, rather than being flat. If there are punctate markings on the surface, the present form will be hard to distinguish, in valve view, from a figure drawn by Schmidt (pl. 144, fig. 10) as of *Corinna elegans* (Heib.) Grun, from the Simbirsk material (Paleocene).

Since the writer failed to find any other genera to which the present form fits better, he tentatively classifies the form as the intercalary band of an unknoun *Denticua*

Occurrences in the present material (Chart 6). The occurrences of this form are sporadical and peculiar, showing high frequencies in a few samples from the lower part of the Onnagawa formation, and Owasawa formation, but it never lasts into more than two samples collected in succession.

Under Pyxilleae, Schütt (1896) grouped small peculiar diatoms whose taxonomic positions were indifinitely known, and left their reclassification for future study as resting spores of other already described species, most probably those of genus *Chaetoceros* and *Rhizosolenia*. Except for a few cases, their mother species remained unknown, since most of the forms were described from fossil materials where the determination of mother species is problematical or impossible. Under the circumstances it has been believed among the workers of fossil materials that it is desirable to leave them as pure morphological taxons for paleontological purpose until more study will be completed.

Subtribe Pyxilleae, Schütt, 1896

Genus ***Dicladia*** Ehrenberg, 1844

Dicladia capreolus Ehrenberg

Pl. 11, figs. 1, 2.

Dicladia capreolus EHRENBERG, 1845, Akad. Wiss. Berlin, Ber., 1884, p. 79 (inaccessible). VAN HEURCK, 1881, Synopsis diatom. Belgique, pl. 106, figs. 15, 16. - DE TONI, 1894, Sylloge algarum, p. 1002.

Size range of measured specimens: 17–40μ in longer girdle view.

Figured specimens: IGPS coll. cat. no. 76669 (pl. 11, fig. 1), longer girdle view 18μ in width, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76670 (pl. 11, fig. 2), longer girdle view 18.3μ in width, from IGPS loc. no. Ao–9, Owasawa formation.

Remarks: The writer follows Hustedt (1930, p. 679) and distinguishes *Dicladia capreolus* from the resting spore of *Chaetoceros mitra* (Bail) Cleve, since the specimens examined, which are almost identical with Van Heurck's figure of *Dicladia capreolus* (*l.c.*, fig. 15) are different from the figures previously given fo *Chaetoceros mitra* (*e. g.* Van Heurck, 1891, pl. 106, 12–13; Hustedt, 1930, p. 678, fig. 384). Namely, the present specimens, as well as Van Heurck's figure, always have two conical elevations on the secondary valve, instead of the simple convex nature of

Ch. mitra; and the two pillars on the primary valve, which become separated at a certain height in *Ch. mitra*, stand separated at their base on the present specimens and on Van Heurck's figure (*l.c.*, fig. 15) of *D. capreolus*. Cleve-Euler may have been right in identifying one (*l.c.*, fig. 14) of Van Heurck's figures of *D. carpeolus* with *Ch. mitra*, but the writer declines to place the entire species in *Ch. mitra* as its synonym as Cleve-Euler did (Cleve-Euler, 1951, 1951, p. 97).

Dicladia pylea Hanna and Grant (1926, p. 142, pl. 16, figs. 4, 5) described from the Miocene deposit of Maria Madre island has *Ch. mitra* appearance than of *D. capreolus*.

Previous records of occurrences: Ehrenberg's type material was from "Richmond", Virginia (De Toni, *l. c.*), middle Miocene Calvert formation (Kanaya, 1957, p. 55). Van Heurck's figures (*l.c.*) were remarked as "des dépôts de Petersburgh et de Naparima", exact locality and geologic age are not determinable.

Occurrences in the present material: The species was found present in several samples of the Onnagawa formation, one of the Owasawa formation, as well as in two samples of the higher horizons, but was always very rare to rare.

Genus ***Stephanogonia*** Ehrenberg, 1844

Stephanogonia Hanzawae Kanaya, n. sp.

Pl. 11, figs. 3–7.

Description: Valve truncated pyramidal with flat top, swollen at the middle, and with wide flat circular brim at the base, turning up shortly at its edge; valve widest at the base, 13–40μ in diameter. Facets 9–20, weakly concave outwardly, and bounded by keels running from the base to top of the valve and terminate in spines at the valve top. Pervalver length (height) relative to diameter varies widely; two valves of a frustule either symmetrical or assymmetrical, but always in the pyramidal shape.

Holotype: IGPS coll. cat. no. 76697 (pl. 11, figs. 3a, 3b, girdle view of a frustule), diameter 30μ, pervalver length 27μ, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Paratypes: IGPS coll. cat. no. 76698 (pl. 11, figs. 4a, 4b, valve view), diameter 34.4μ; IGPS coll. cat. no. 76699 (pl. 11, figs. 5a, 5b, girdle view of a valve), diameter 16.4μ, pervalver length 16.4μ; IGPS coll. cat. no. 76700 (pl. 11, figs. 6a, 6b, girdle view of a valve), diameter 16.4μ, pervalver length 17μ; IGPS coll. cat. no. 76701 (pl. 11, fig. 7, girdle view of a frustule), diameter 13.7μ, pervalver length 22.8μ+12μ). Locality: all from the same locality as holotype.

Remarks: In the early stage of his study, the present writer distinguished two forms in *Stephanogonia* in his samples, mainly on the basis of the difference in height of a valve relative to the valve diameter. The later findings of the frustules with their two valves in different height, however, made such a separation meaningless. In an extreme case the writer found that two valves of a frustule are different not only in height, but also in valve diameter.

Among *Stephanogonia* previously described, the figure of *Stephanogonia polygona* Ehrenberg drawn by Van Heurck (1881, pl. 83, ter., 16, from "Richmond", Virginia, mid. Miocene) resemble the new species, in having both valves of a frustule in pyramidal shape. The new species is distinguished from that one by the valves being swollen at the middle.

The present writer follows Van Heurck (*l. c,*), and Cleve-Euler (1952, p. 110) who included under *Stephancgonia* also the diatom with both valves of a frustule in pyramidal, besides diatoms with one valve pyramidal, and the other more or less flat.

The species is named for Professor S. Hanzawa of the Institute of Geology and Paleontology, Tohoku University.

Occurrences in the present material (Chart 6) : The species was found in most of the samples of the assemblages A, and B in the Onnagawa formation, while it was lacking in the assemblage C. An occurrence at the higher horizon, Ao–24 of the Maido formation, however, indicates that the presence of this species alone is not dependable for stratigraphic purposes. The species is chosen as one of the eight marker species whose joint occurrences define the assemblage B (*Coscinodiscus Yabei* assemblage) in the Onnagawa formation (Chart 7).

Genus ***Xanthiopyxis*** Ehrenberg, 1845

Karsten (1928, in Engler and Prantl, p. 301) diagnosed genus *Xanthiopyxis* Ehrenberg as follows:

> Schalenansicht kreisförmig bis elliptisch. Oberflache meist hyaline, weder retikuliert noch areoliert, noch granuliert, mit zerstreuten, kleinen Stacheln.

He placed *Omphalotheca* Ehrenberg, and *Pyxidicula* Ehrenberg under *Xanthiopyxis* as synonymus.

The genus has been generally regarded as resting-spores of the genus *Chaetoceros* (Mills, 1934, p. 1682; Lohman, 1938, p. 91), but no correlation between the described *Xanthiopyxis* and known resting-spores of living *Chaetoceros* has ever been successful (Cleve-Euler, 1951, p. 109).

While examining the present material, the writer frequently met small spiny diatoms referable to *Xanthiopyxis*, but no *Chaetoceros* frustules were found preserved. With the helps of papers by Hustedt (1930, pp. 625–767) and Cleve-Euler (1951, pp. 90–110), in which both authors skillfully described resting-spores of

Chaetoceros, and effort has been directed to relate the fossil spore-like diatoms in the present samples to the resting-spores of known *Chaetoceros*. Of the specimens examined one form shows similarity close enough to assume that the mother species was *Chaetoceros seiracanthus* Grunow; some were, by analogy, almost certain on their being of resting-spores of *Chaetoceros*, though their mother species were not determinable; and still others were not at all likely to be of the resting-spores of *Chaetoceros*.

Brun and Tempère (1889, p. 70) listed following *Chaetoceros* species as were found in their Japanese material, "Calcaire de Yédo et de Sendai". They are:
Chaetoceros clavigerum (Fr. Jos. land, 5, 51) var. : not a *Cheatoceros*.
Chaetoceros didymum Ehrenberg : for the resting-spore see Cleve-Euler (1951, p. 99, fig. 192d).
Chaetoceros distans Cleve var. *subsecunda* Grunow (V.HK., 82 bis., 6) : by Hustedt, a synonym of *Chaetoceros subsecundus* (Grun.) Hustedt (Hustedt, 1930, p. 709, fig. 404), and by Cleve-Euler, a synonym of *Chaetcceros diadema* (Ehr.) Grunow (Cleve-Euler, 1951, p. 103).
Chaetoceros incurvum Baily (1856, M.J., 7, 9 a 11) : see Wolle (1890, pl. 65, figs. 9, 10).
Chaetoceros javanicum Cleve (Java, 2, 13) : a synonym of *Chaetoceros affinis* (Hustedt, 1930, p. 695, fig. 396).
Chaetoceros Ralfsii Cleve (Java 3, 3) et (V. HK., 82 bis., 3) : a synonym of *Chaeteceros Vanheurckii* Gran (Gran and Angust, 1931, p. 476, fig. 60b; Cupp, 1943, p. 123, fig. 77).

Brun and Tempère appeared to have identified the above mentioned species in the states of resting-spore, or by isolated setae. None of the present forms, however, are similar enough to identify with the resting-spores of those species found by them.

Proposing new species of *Xanthiopyxis* for the present forms is as problematical as to identify them forcedly with existing *Chaetoceros* species by analogous appearance of resting-spores in various degrees, since the present writer has no working knowledge on the morphological variation of resting-spores of living *Chaetoceros*. Hence, he has decided to take an expedience; the group them into pure morphological taxons, and reserves their naming for future study.

Artificial key to *Xanthiopyxis* in the present samples

I. Both valves are spiny.

A. Valve ovate to elongate ovate, broadly arched.

1. Valve ovate, smaller, with spines throughout the surface. . *X. oblonga*

2. Valve elongate-ovate, larger. Robust spines present except in a hyaline area at the middle portion of valve surface . . *X. acrolopha*

B. Valve circular, either valve more narrowly arched.
1. Spines similar on both valves ....X. sp. 1
2. Spine coarser on a valve then on the other ....X. sp. 2
3. A few stronger spines present at the central part of the more narrowly arched valve ....X. sp. 3

II. Either valve is spiny.

A. A valve smooth, the other spiny.
1. Spiny valve narrowly arched ....X. sp. 4
2. Spiny valve broadly arched ....X. sp. 5

B. One valve spiny, the other keeled ....X. sp. 6

Xanthiopyxis acrolopha Forti

Pl. 11, fig. 8.

Xanthiopyxis acrolopha FORTI, 1912, Nuova Notarisia, vol. 23, p. 84 (inaccessible). - FORTI, 1913, Contr. Diatom. 13, Atti de Reale Ist. Vento, Sci. Lett. Arti, vol. 72, pt. 2, p. 1556, pl. 12 (2), figs. 22, 24, 27, 28, 30-37. - HANNA, 1927, Jour. Paleont., vol. 1, no. 2, p. 124, pl. 21, figs. 10, 11.

Figured specimen : IGPS coll. cat. no. 76719 (pl. 11, figs. 8a, 8b, valve view), length of longer axis 50μ from IGPS loc. no. Ak-55, Shinzan diatomaceous mudstone member, Onnagawa formation.

Remarks : The species is characterized by the depressed hyaline area at the middle portion of valve where both sides are somewhat constricted. Valves are larger, and more elongated, and spines are far much robust than that of *Xanthiopyxis oblonga*. The present species does not seem to represent the resting-spore of the genus *Chaetoceros*.

Previous records of occurrences : The species was described from Miocene deposits of Italy, where it was reported to be common. Hanna (*l.c.*) found the species in the "lower Miocene shale" from Phoenix Canyon near Coalinga, Fresno County, California. The locality is now considered to be of the Refugian Stage, early Oligocene (Kanaya, 1957, p. 52).

Occurrences in the present material (Chart 6) : The species was found present in two samples from the Onnagawa formation.

Xanthiopxyis oblonga Ehrenberg

Pl. 11, figs. 9, 10.

Xanthiopyxis oblonga EHRENBERG, 1845, K. Akad. Wiss. Berlin, Ber., 1844, p. 273

(inaccessible). - EHRENBERG, 1854, Microgeologie, 1854, pl. 33, gr. 17, fig. 17 (inaccessible). - DE TONI, 1894, Sylloge algarum, p. 1155. - FORTI, 1913, Contr. Diatm. 13, Atti de Reale Ist. Veneto, Sci. Lett. Arti, vol. 72, pt. 2, pl. 12 (2), fig. 11. - KANAYA, 1957, Sci. Rep. Tohoku Univ., Sendai, 2d ser. (Geology), vol. 28, p. 116, pl. 8, figs. 12a, 12b.

Size range of measured specimens: longer axis in valve view, 15–25μ excluding spines.

Figured specimens: IGPS coll. cat. no. 76720 (pl. 11, fig. 9), longer axis 18.4μ, shorter axis 15μ, from IGPS loc. no. Ak–44–2, Hirasawa diatomaceous mudstone member, Onnagawa formation; IGPS coll. cat. no. 76721 (pl. 11, fig. 10, slightly tilted), longer axis 17μ from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: The species has a long geologic history ranging from upper Eocene (Kanaya, *l.c.*) to Pliocene in age (Lohman, 1938, p. 83; p. 91).

Occurrences in the present material (Chart 6): Seven other forms of *Xanthiopyxis* than *X. acrolopha* were counted together. The knowledge is premature to discuss the stratigraphic values of this group of diatoms, which undoubtedly supply important data from the paleoecological standpoint when their mother species will be ascertained.

Xanthiopyxis sp. 1

Pl. 11, fig. 11.

Figured specimen: IGPS coll. cat. no. 76722 (pl. 11, fig. 11, girdle view), 11.5μ in diameter, from IGPS loc. no. Ao–12, Owasawa formation.

Remarks: A line of minute round markings, 10 in 10μ, may be the traces of parallel spines, as known on *Chaetoceros Vanheurckii* Gran. In this respect, the form can not be identified with resting-spores of *Chaetoceros anastomosana* var. *externa* Hustedt (1930, p. 743, fig. 430; Cleve-Euler, 1951, p. 101, fig. 196c). Resting-spores of *Chaetoceros Vanheurckii* Gran, on the other hand, has never been figured as to have both valves equally spiny (Gran and Angust, p. 476, fig. 60a, b; Cupp, 1943, p. 117, fig. 77).

Xanthiopyxis sp. 2

Pl. 11, fig. 12.

Figured specimen: no. 447 (pl. 11, figs. 12a, 12b, girdle view), diameter 11.5μ, length of a spore 16.4μ, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: Spines are coarser on one valve than the other. The valve with finer spines is more highly arched than the other. A line of fine markings is present on rims. No known *Cheatoceros* resting-spores is quite comparable to the present form. Nevertheless its being of resting-spore of *Chaetoceros* seems to be certain.

Xanthiopyxis sp. 3

Pl. 11, fig. 13.

Figured specimen: IGPS coll. cat. no. 76724 (pl. 11, fig. 13, girdle view), 16μ in diameter, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: Longer spines of the central part of narrowly arched valve seems to suggest that the form is closely related to the resting-spores of *Chaetoceros affinis* Lauder or *Chaetoceros seiracanthus* Grunow. The published figures of *Ch. affinis* never have parallel spines at the rim of resting-spore, while the line or minute markings found at the rims of the present form seems to be the trace of the parallel spines once existed.

Chaetoceros seiracanthus was described to have the parallel spines at the rim (Cleve-Euler, 1951, p. 104, fig. 209; Hustedt, 1930, p. 711, fig. 405c, d). Should the assumption that the minute markings are remains of parallel spines be warranted, the form can be identified with the resting-spores of *Chaetoceros seiracanthus* Grunow

Xanthiopyxis sp. 4

Pl. 11, fig. 14.

Figured specimen: IGPS coll. cat. no. 76725 (pl. 11, fig. 14, girdle view), diameter 11.4μ, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: With one spiny valve narrowly arched, the other free from spines. A line of minute markings is placed on rim.

Xanthiopyxis sp. 5

Pl. 11, fig. 15.

Figured specimen: no. 162 (pl. 11, figs. 15a, 15b), diameter 22.8μ, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation.

Remarks: The spiny valve is more broadly arched than that of *X.* sp. 4, and a line of markings is placed at both rims, instead of on one rim. Both forms have the outline somewhat similar to the resting-spore of *Chaetoceros affinis*, if they resemble any, but lacking spine on one valve, and the line of fine markings at either or both rims, make this comparison improbable. *X*. sp. 5 is almost identical with specimens skillfully separated by Hanna from Pliocene hard concretionary limestone (Hanna, 1930, p. 192, pl. 14, fig. 11). They were found preserved forming a chain, as long as to have 15 frustules in one chain. Hanna called them *Omphalotheca* sp., and took this chain forming nature to prove that the species does not have an intimate relation with *Chaetoceros*, but is a distinct species. It is probably so, but there seems to be another way to explain the occurrence: they are resting-spores which have been preserved as they were in a chain forming mother cells, the wall of which had been dissolved.

Xanthiopyxis sp. 6

Pl. 11, fig. 16.

Figured specimen: IGPS coll. cat, no. 76734 (pl. 11, fig. 16, girdle view), diameter 11.5μ, length of a cell 22.8μ, from IGPS loc. no. Ak–57, Shinzan diatomaceous mudstone member, Onnagawa formation.
Remarks: With one valve keeled, and the other valve with robust spines. Placing this form under *Xanthiopyxis* is questionable. The form appears to be not the resting-spore of *Chaetoceros*.

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PLATE I

Figs. 1a, 1b. *Melosira granulata* (Ehr.) Ralfs. IGPS coll. cat. no. 76682, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member of Onnagawa formation. Diameter 15μ. × 1500

Fig. 2. *Melosira granulata* (Ehr.) Ralfs forma *curvata* (Grun.) Hustedt. IGPS coll. cat. no. 76683, from IGPS loc. no. AK–44–1, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 6μ. × 1500

Fig. 3. *Melosira sol* (Ehr.) Kütz. IGPS coll. cat. no. 76684, from IGPS loc. no. Ao-12, Owasawa formation. Diameter 43μ. × 800

Figs. 4a, 4b. *Melosira sulcata* (Ehr.) Kütz. IGPS coll. cat. no. 76685, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 8μ, × 1500

Fig. 5. *Melosira sulcata* (Ehr.) Kütz. IGPS coll. cat. no. 76686, from IGPS loc. no. Ak-53, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 16μ. × 1500

Fig. 6. *Melosira sulcata* (Ehr.) Kütz. IGPS coll. cat. no. 76687, from IGPS loc. no. Ak–70–3, Yorinobezawa formation. Diameter 16μ. × 1500

Fig. 7. *Melosira sulcata* (Ehr.) Kütz. IGPS coll. cat. no. 76688, from IGPS loc. no. Ak–68, Shinzan diatomaceous mudstone member of Onnagawa formation. Diameter 33μ, Valve view of two valves. × 1500

Figs. 8a, 8b. *Endictya japonica* Kanaya, n. sp. Holotype. IGPS coll. Cat. no. 76671, from IGPS loc. no.Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 24μ. × 1000

Figs. 9a, 9b. *Endictya japonica* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76672, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 25μ. × 1000

Figs. 10a, 10b. *Endictya japonica* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76673, from IGPS loc. no. Ao–13, Owasawa formation. Diameter 24.2μ. × 1000

Figs. 11a, 11b. *Stephanopyxis* cfr. *ferox* (Grev.) Ralfs. IGPS coll. cat. no. 76702, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 36.5μ. × 800

Fig. 12. *Stephanopyxis* cfr. *ferox* (Grev.) Ralfs. IGPS coll. cat. no. 76703, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 39μ. × 800

Figs. 13a, 13b. *Stephanopyxis* cfr. *ferox* (Grev.) Ralfs. IGPS coll. cat. no. 76704, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 52.5μ. 13a : a valve view with the valve surface down, focused at the valve base. × 800

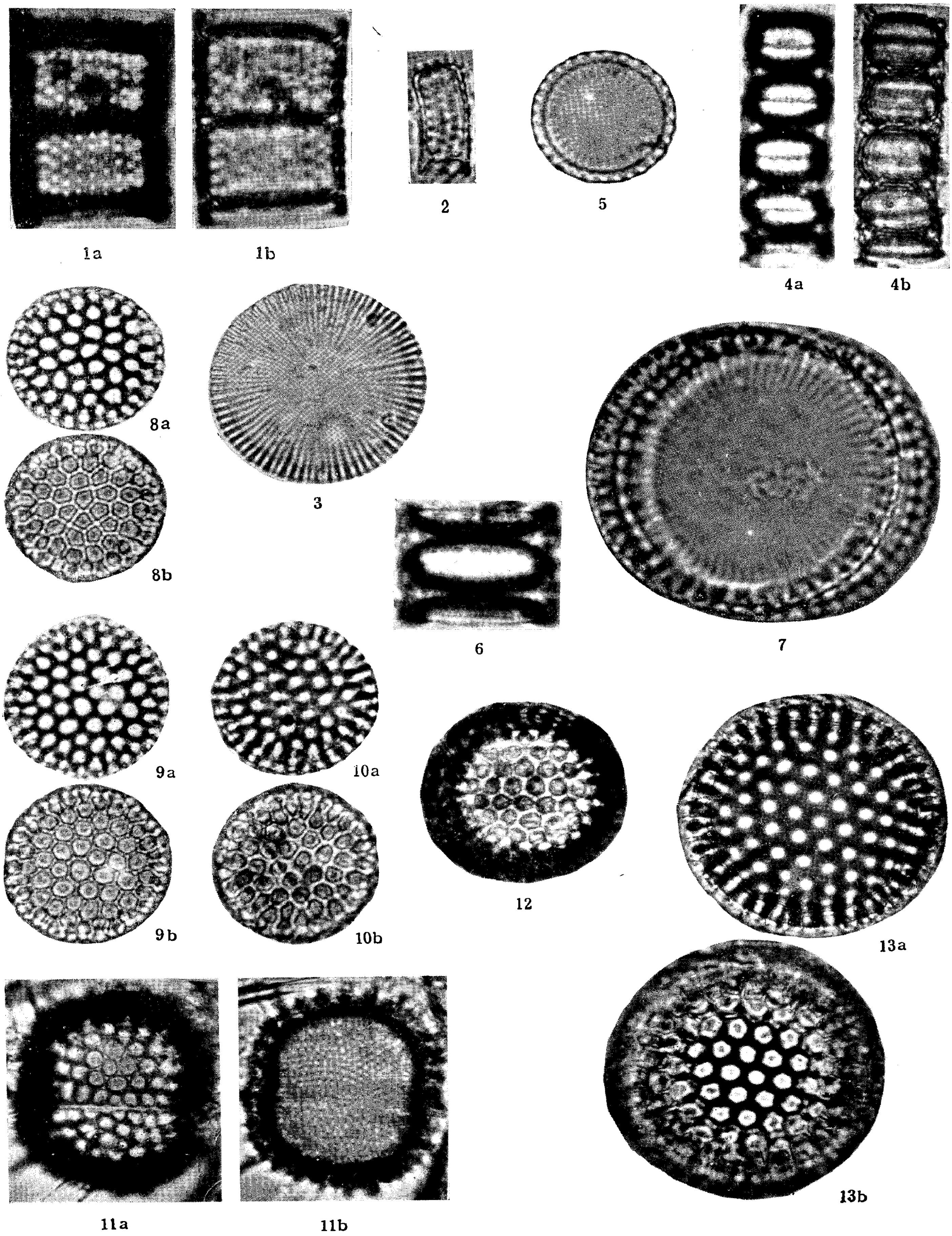
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PLATE II

Figs. 1a, 1b. *Stephanopyxis* cfr. *nipponica* Gran and Yendo. IGPS coll. cat. no. 76705, from IGPS lcc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 25μ. $\times$ 800

Figs. 2a, 2b. *Stephanopyxis Schenckii* Kanaya, n. sp. Holotype. IGPS coll. cat. no. 76706, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 57μ. $\times$ 800

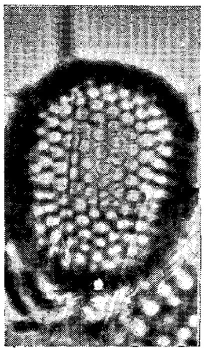
Figs. 3a, 3b. *Stephanopyxis Schenckii* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76707, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 62μ. $\times$ 800

Figs. 4a, 4b. *Stephanopyxis Schenckii* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76708, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 39μ. Valve views slightly tilted. $\times$ 800

Fig. 5. *Stephanopyxis turris* (Grev. et. Arnott) Ralfs. IGPS coll. cat. no. 76709, from IGPS loc. no. Ao–13, Owasawa formation. Pervalver length of a frustule 44μ. $\times$ 800

Figs. 6a, 6b. *Stephanopyxis turris* (Grev. et. Arnott) Ralfs. IGPS coll. cat. no. 76710, from IGPS loc. no. Ao–13, Owasawa formation. Pervalver length of a frustule 75μ. $\times$ 800

Figs. 7a, 7b. *Stephanopyxis turris* (Grev. et Arnott) Ralfs. IGPS coll. cat. no. 76711, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Pervalver length of a valve 45.6μ. $\times$ 800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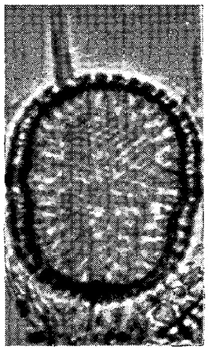
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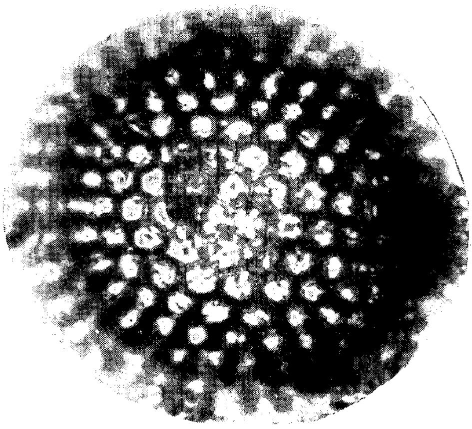
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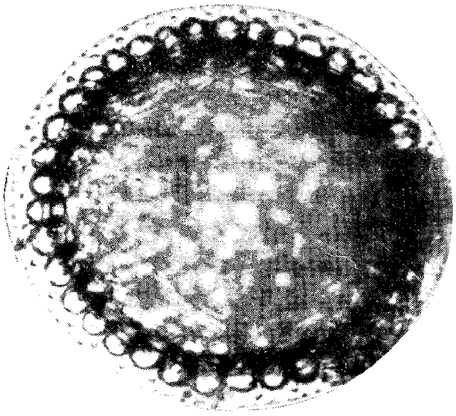
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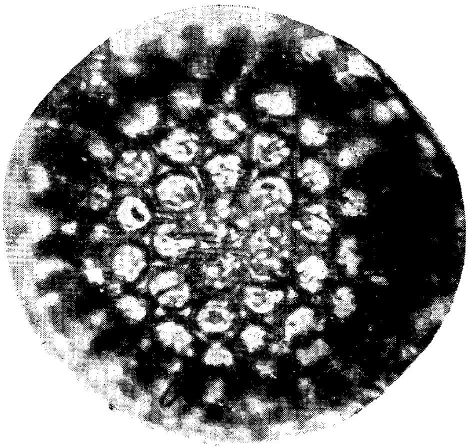
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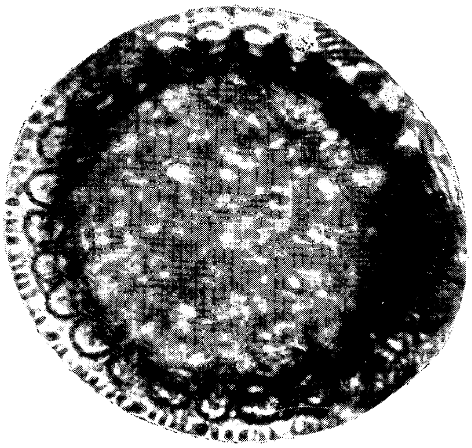
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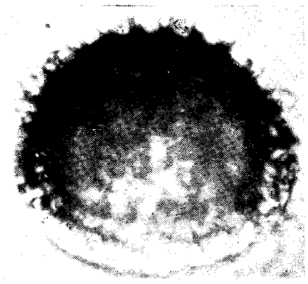
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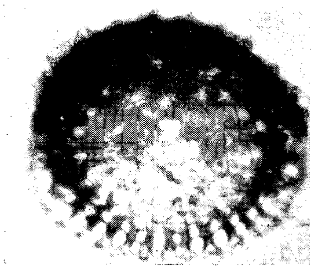
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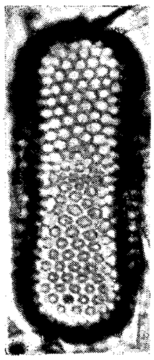
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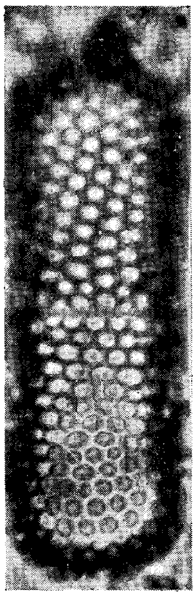
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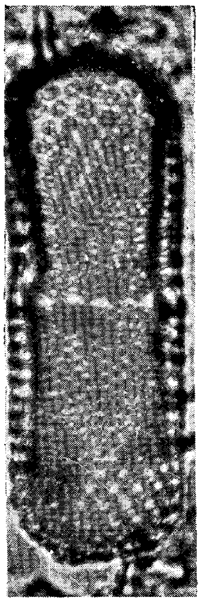
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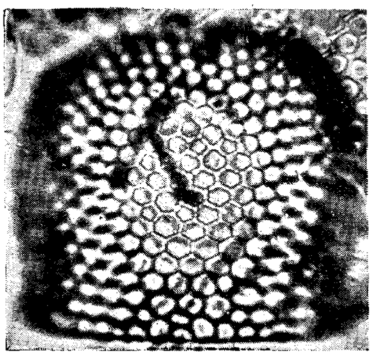
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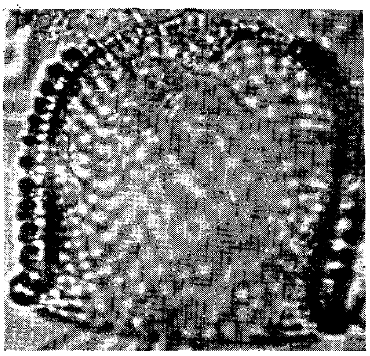
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PLATE III

Figs. 1a, 1b. *Stephanopyxis ? limbata* Ehr. var. *Crista - Galli* Tempère and Brun. IGPS coll. cat. no. 76712, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Length of apical axis 74μ. × 800

Fig. 2. *Thalassiosira decipiens* (Grun.) Jørgensen. IGPS coll. cat. no. 76713, from IGPS loc. no. Ak–59, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 23μ. × 1000

Fig. 3. *Thalassiosira decipiens* (Grun.) Jørgensen. IGPS coll. cat. no. 76714, from IGPS loc. no. Ak–67, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 22.8μ. A broken specimen. × 1000

Fig. 4. *Coscinodiscus argus* Ehr. IGPS coll. cat. no. 76632, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 98μ. Margin partly broken. × 640

Fig. 5. *Coscinodiscus curvatulus* Grun. var. *odontodiscus* (Grun.) Hustedt. IGPS coll. cat. no. 76633, from IGPS loc. no. Ak–67, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 55μ. × 800

Fig. 6. *Coscinodiscus elegans* Grev. IGPS coll. cat. no. 76634, from IGPS loc. no. Ao–9, Owasawa formation. Diameter 17μ. × 1000

Fig. 7. *Coscinodiscus elegans* Grev. IGPS coll. cat. no. 76635, from IGPS loc no. Ao–9, Owasawa formation. Diameter 19.8μ. × 1150

Fig. 8. *Coscinodiscus Endoi* Kanaya, n. sp. Holotype. IGPS coll. cat. no. 76636, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 45μ. × 800

Fig. 9. *Coscinodiscus Endoi* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76637, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 61.5μ. × 800

Figs. 10a, 10b. *Coscinodiscus Endoi* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76638, from IGPS loc. no. Ao–9, Owasawa formation. Diameter 30μ. × 1000

Figs. 11a, 11b. *Coscinodiscus Endoi* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76639, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 20.5μ. × 1000

Figs. 12a, 12b. *Coscinodiscus excentricus* Ehr. IGPS coll. cat. no. 76640, from IGPS loc. no. Ak–59, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 39μ. × 800

Figs. 13a, 13b. *Coscinodiscus excentricus* Ehr. IGPS coll. cat. no. 76641, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 40.5μ. × 800

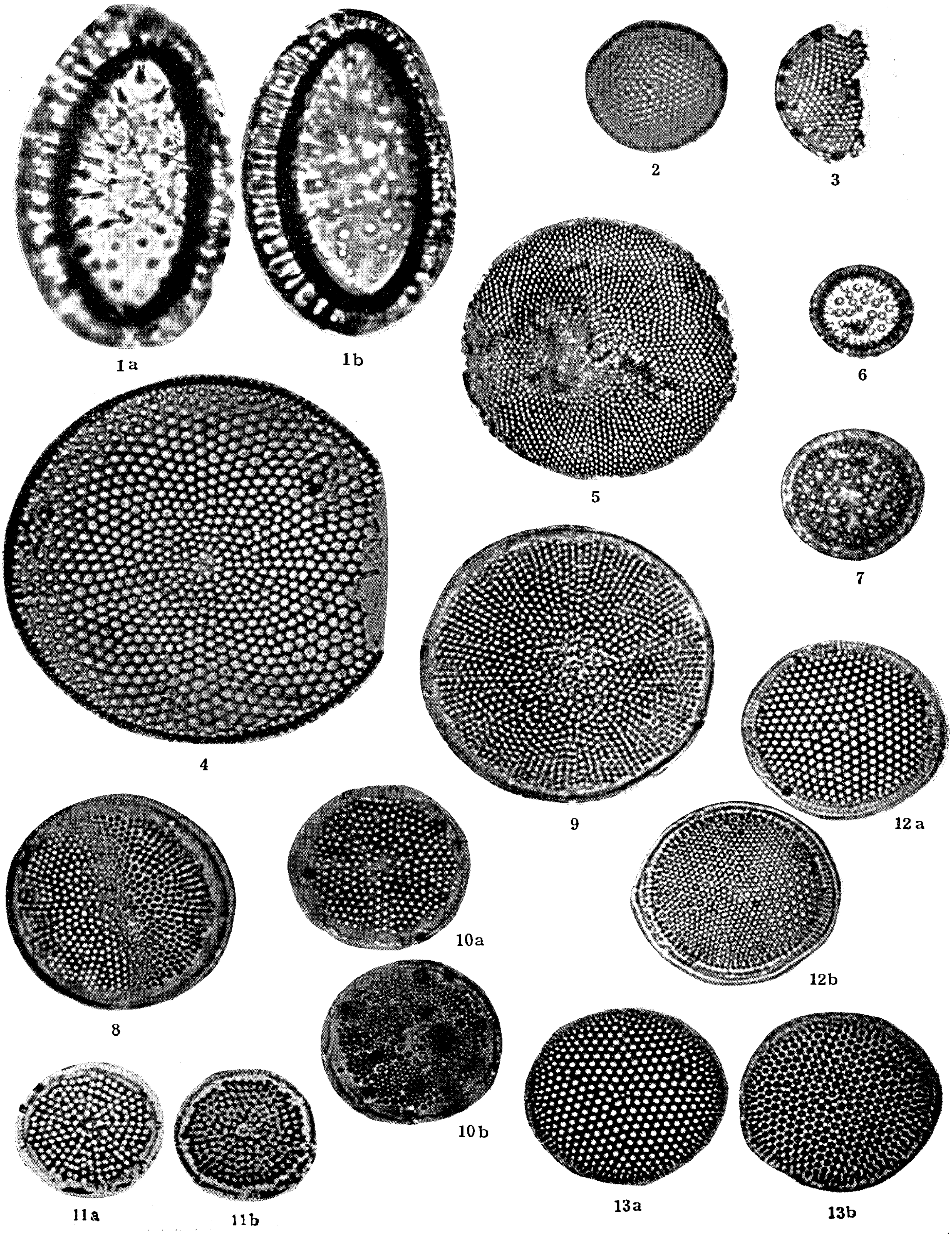
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PLATE IV

Figs. 1a, 1b. *Coscinodiscus hirosakiensis* Kanaya, n. sp. Holotype. IGPS coll. cat. no. 76643, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 27.5μ. × 1000

Figs. 2a, 2b. *Coscinodiscus hirosakiensis* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76644, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 29.6μ. × 1000

Fig. 3. *Coscinodiscus lineatus* Ehr. IGPS coll. cat. no. 76645, from IGPS loc. no. Ak–46, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 55μ. × 800

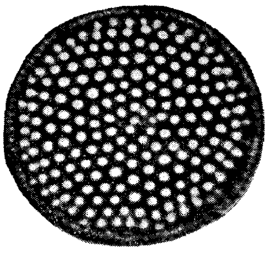
Figs. 4a, 4b. *Coscinodiscus marginatus* Ehr. IGPS coll. cat. no. 76646, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 86.5μ. × 600

Figs. 5a, 5b. *Coscinodiscus marginatus* Ehr. IGPS coll. cat. no. 76647, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 47.9μ. × 800

Fig. 6. *Coscinodiscus marginatus* Ehr. IGPS coll. cat. no. 76648, from IGPS loc. no. Ak–49, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 175μ. × 460

Fig. 7. *Coscinodiscus oculus-iridis* Ehr. IGPS coll. cat. no. 46649, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 114μ. × 640

Fig. 8. *Coscinodiscus Temperi* Brun. IGPS coll. cat. no. 76653, from IGPS loc. no. Ao–13, Owasawa formation. Apical axis 48.5μ. × 800



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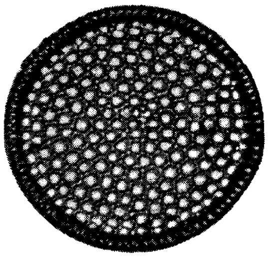

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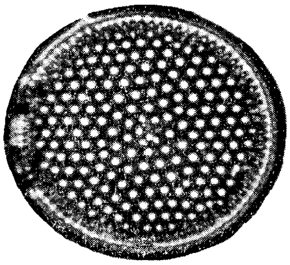

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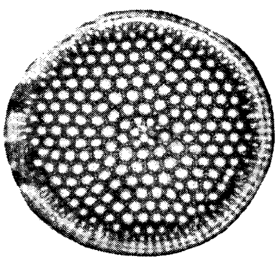

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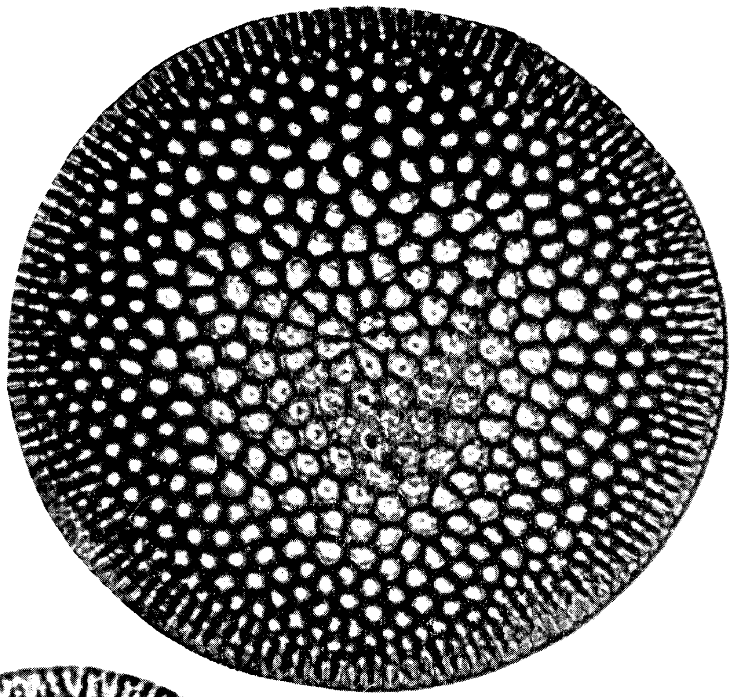

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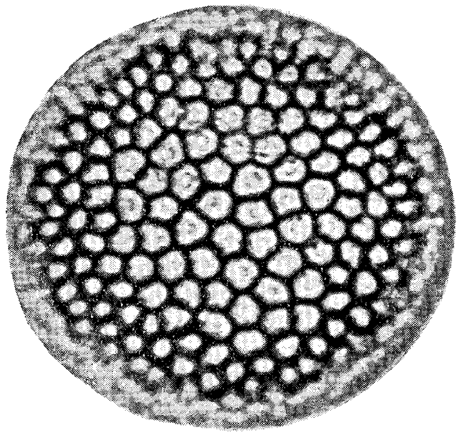

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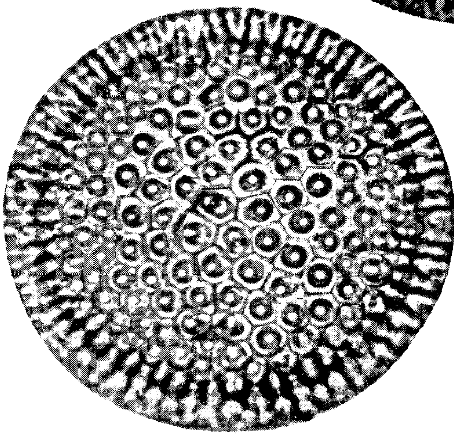

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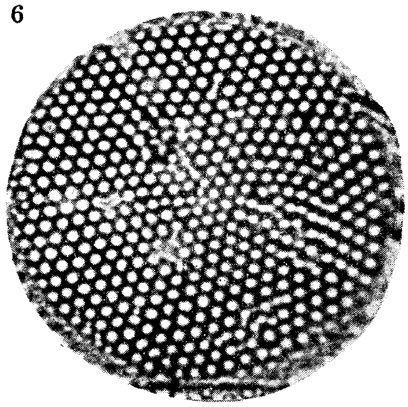

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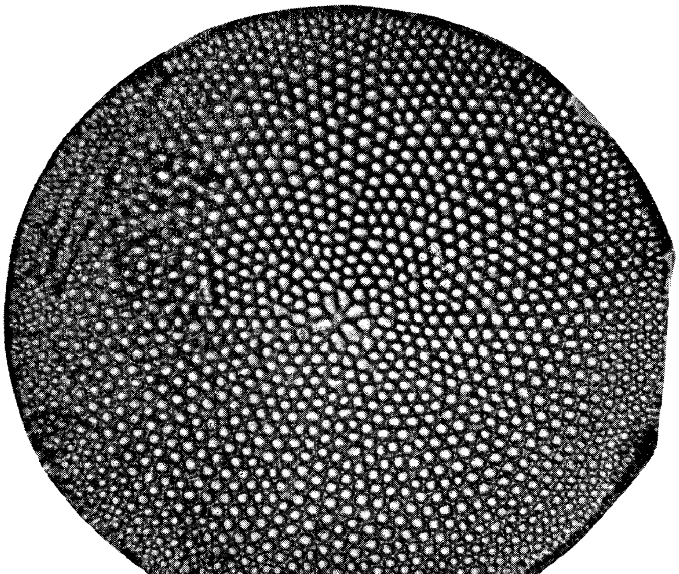

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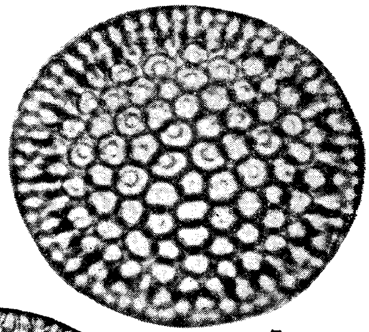

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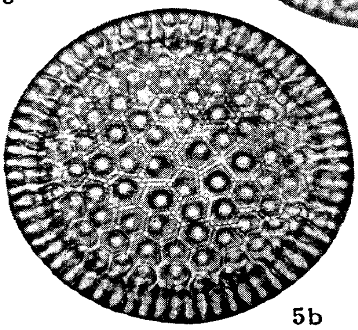


5b

PLATE V

Figs. 1a, 1b. *Coscinodiscus radiatus* Ehr. IGPS coll. cat. no. 76651, from IGPS loc. no. Ak–48–5, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 96μ. × 600

Fig. 2. *Coscinodiscus Rothii* (Ehr.) Grun. IGPS coll. cat. no. 76652, from IGPS loc. no. Ak–59, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 42μ. × 1000

Fig. 3. *Coscinodiscus vetustissimus* Pantocsek. IGPS coll. cat. no. 76654, from IGPS loc. no. Ao–10, Owasawa formation. Diameter 59.5μ. × 800

Fig. 4. *Coscinodiscus vetustissimus* Pantocsek. IGPS coll. cat. no. 76655, from IGPS loc. no. Ao–13, Owasawa formation. Diameter 52.5μ. × 800

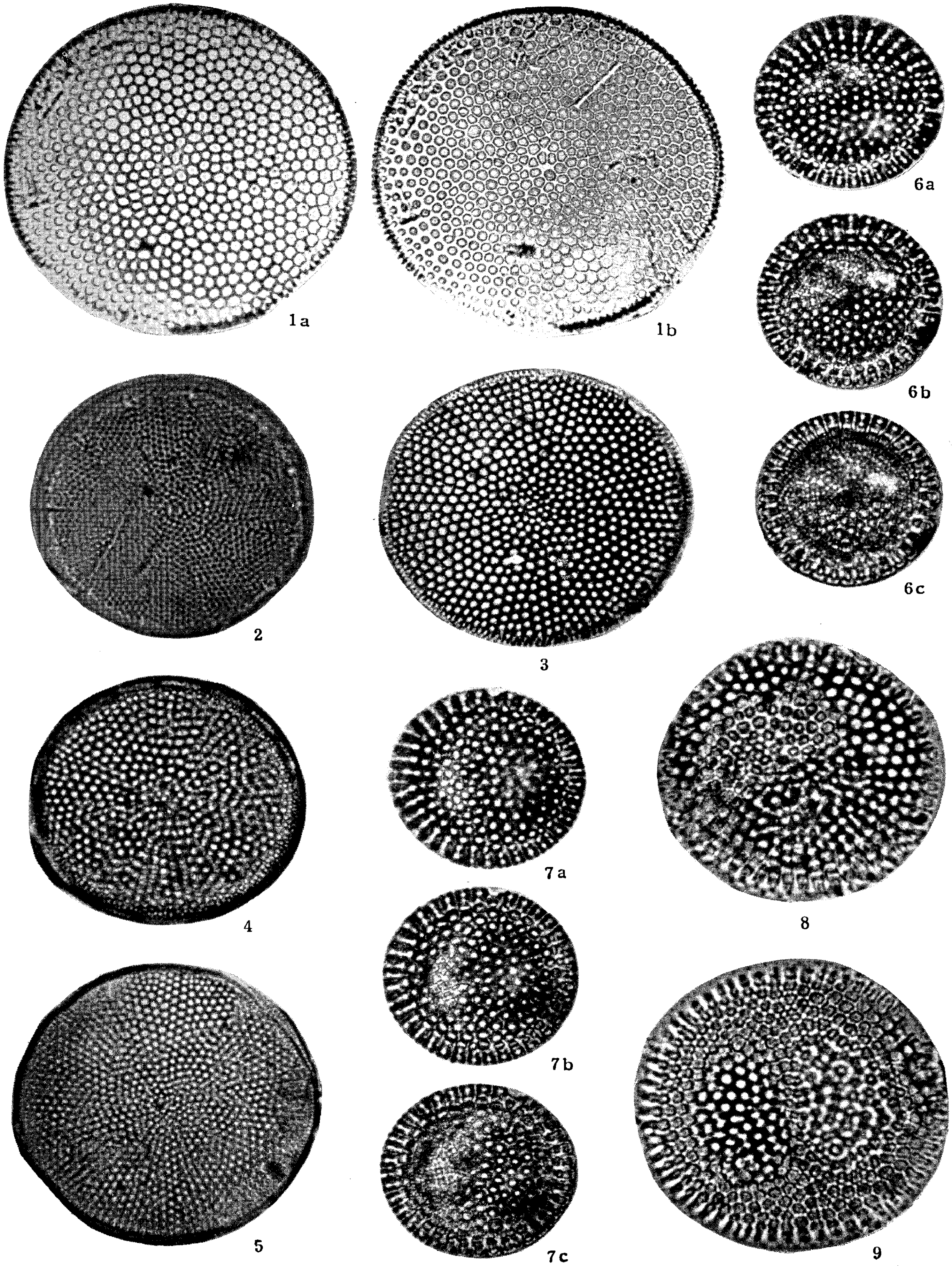
Fig. 5. *Coscinodiscus vetustissimus* Pantocsek. IGPS coll. cat. no. 76656, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 80μ. × 600

Figs. 6a, 6b, 6c. *Coscinodiscus Yabei* Kanaya, n. sp. Holotype. IGPS coll. cat. no. 76657, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 28.5μ. × 1000

Figs. 7a, 7b. 7c. *Coscinodiscus Yabei* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76658, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 30μ. × 1000

Fig. 8. *Coscinodiscus Yabei* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76659, from IGPS loc. no. Ak–46, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 43.2μ. × 1000

Fig. 9. *Coscinodiscus Yabei* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76660, from IGPS loc. no. Ak–46, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 47μ. × 1000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1b
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8
7b
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7c
9

PLATE VI

Fig. 1. *Cladogramma californicum* Ehr. IGPS coll. cat. no. 76625, from IGPS loc. no. Ao–13, Owasawa formation. Diameter 30μ. × 800

Fig. 2. *Arachnoidiscus Ehrenbergii* Bail. ex Ehr. IGPS coll. cat. no. 76621, from IGPS loc. no. Ao–9, Owasawa formation. Diameter 93.5μ. × 600

Fig. 3. *Arachnoidiscus Ehrenbergii* Bail. ex Ehr. IGPS coll. cat. no. 76622, from IGPS loc. no. Ao–13, Owasawa formation. Diameter 176μ. × 400

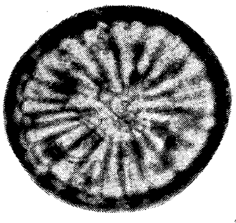
Figs. 4a, 4b. *Actinoptychus senarius* (Ehr.) Ehr. IGPS coll. cat. no. 76618, from IGPS loc. no. Ao–9, Owasawa formation. Diameter 55μ. × 800

Fig. 5. *Actinoptychus senarius* (Ehr.) Ehr. IGPS coll. cat. no. 76619, from IGPS loc. no. Ao–13, Owasawa formation. Diameter 35.7μ. × 800

Fig. 6. *Actinoptychus* cfr. *splendens* (Shadb.) Ralfs var. *Halionyx* Grun, ex Van Heurck, IGPS coll. cat. no. 76620, from IGPS loc. no. Ao–13, Owasawa formation. Diameter 72.5μ. × 800

Fig. 7. *Asteromphalus moronensis* (Grev.) Ratt, IGPS coll. cat. no. 76623, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation. Radius c.a. 43.5μ. A broken specimen. × 700

Figs. 8a, 8b. *Aulacodiscus amoenus* Grev. var. *hungaricus* Pant. IGPS coll. cat. no. 76624, from IGPS loc. no. Ao–13, Owasawa formation. Diameter, c.a. 100μ. A broken specimen. × 600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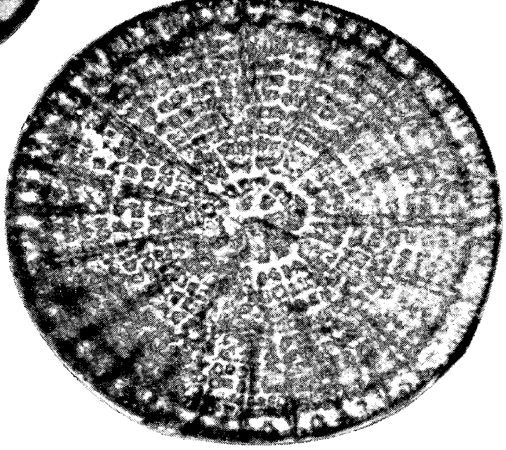
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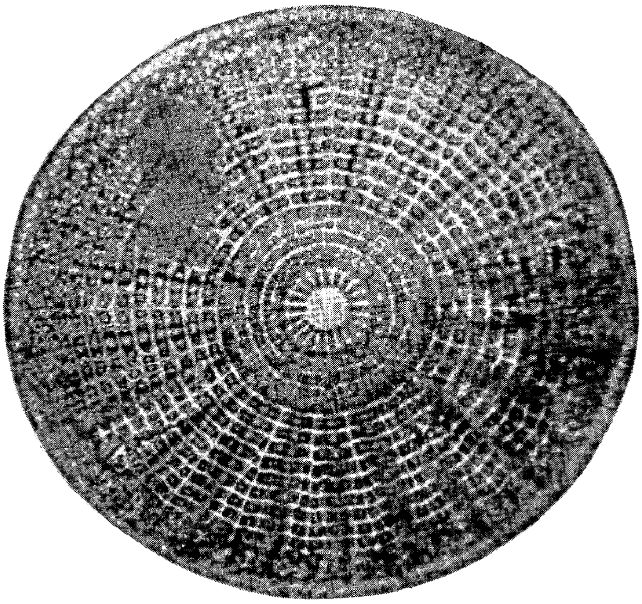
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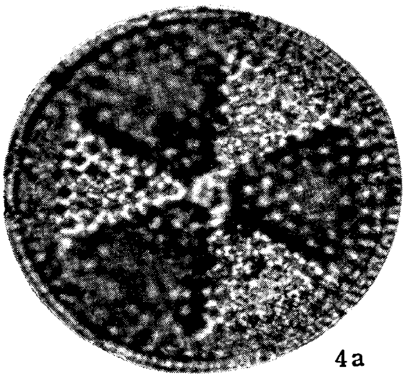
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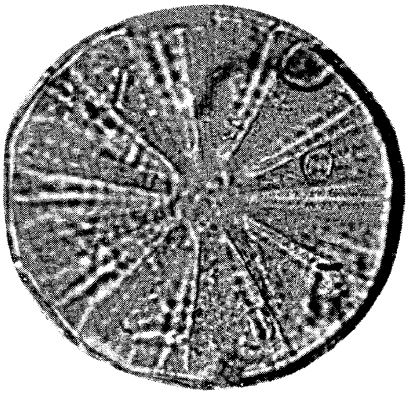
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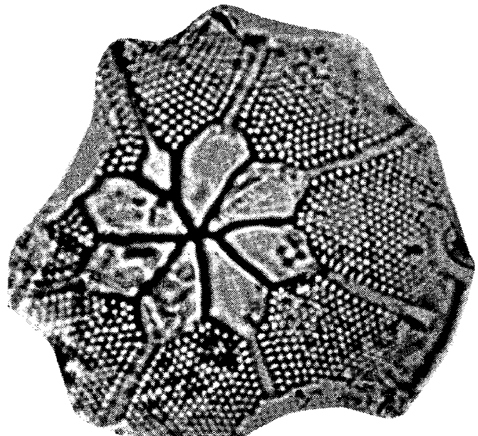
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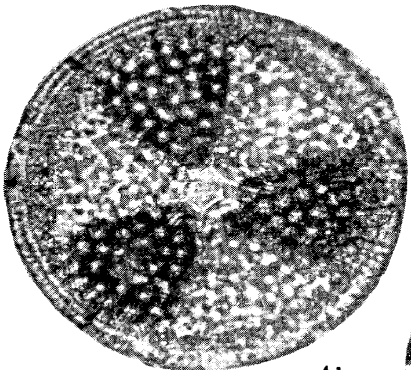
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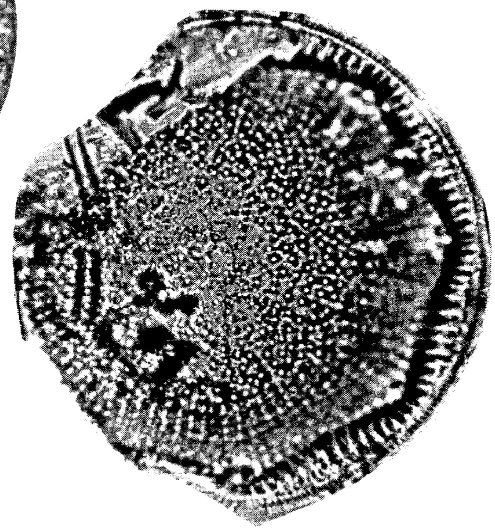
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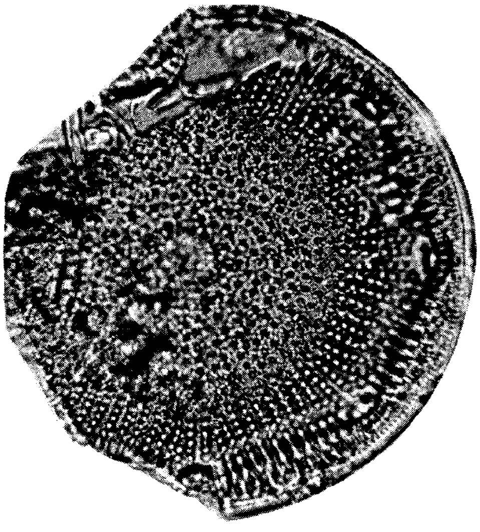
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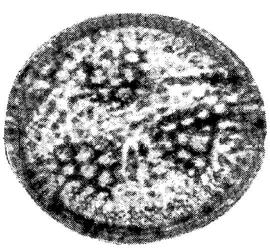
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PLATE VII

Figs. 1a, 1b. *Actincoyclus Ehrenbergii* Ralfs. IGPS coll. cat. no. 76601, from IGPSl oc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 64μ. Margin paıtly broken. × 800

Fig. 2. *Actinocyclus Ehrenbergii* Ralfs var. *tenella* (Brev.) Hustedt. IGPS coll. cat. no. 76602, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 29.6μ. × 1000

Fig. 3. *Actinocyclus Ehrenbergii* Ralfs var. *tenella* (Brev.) Hustedt. IGPS coll. cat. no. 76603, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 38.8μ. × 800

Fig. 4. *Actinocyclus ellipticus* Grun. var. *javanica* Reinhold. IGPS coll. cat. no. 76604, from IGPS loc. no. Ak–56, Shinzan diatomaceous member, Onnagawa formation. Apical axis 52.5μ. × 800

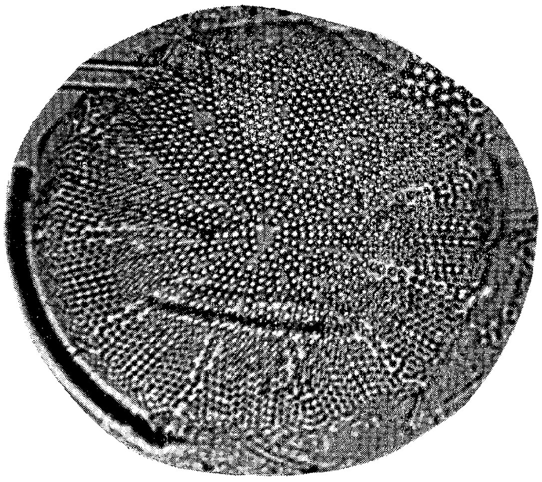
Fig. 5. *Actinocyclus ellipticus* Grun. var. *javanıca* Reinhold. IGPS coll. cat. no. 76605, from IGPS loc. no. Ak–61, Shinzan diatomaceous mudstone member, Onnagawa formation. Apical axis 37.5μ. × 800

Figs. 6a, 6b. *Actinocyclus ingens* Ratt. IGPS coll. cat. no. 76606, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 58μ. × 800

Fig. 7. *Actinocyclus ingens* Ratt, IGPS coll. cat. no. 76607, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 44.4μ. × 800

Figs. 8a, 8b. *Actınocyclus ingens* Ratt. IGPS coll. cat. no. 76608, from IGPS loc. no. Ao–9, Owasawa formation. Diameter 60μ. × 700

Fig. 9. *Actinocyclus ingens* Ratt. IGPS coll. cat. no. 76609, from IGPS loc. no. Ao–12, Owasawa formatıon. Diameter 64μ. × 700



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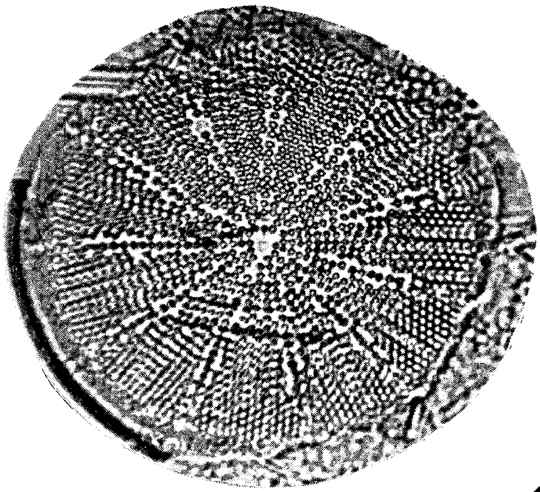

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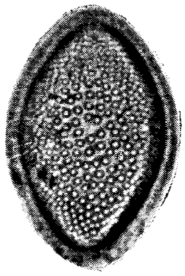

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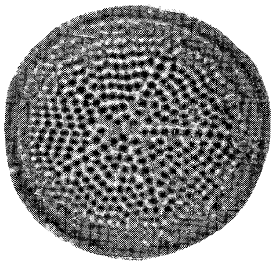

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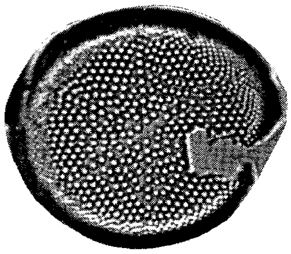

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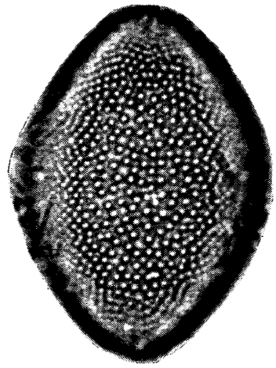

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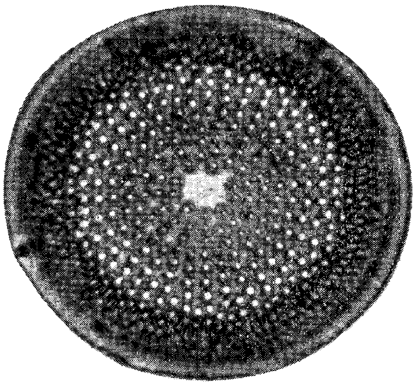

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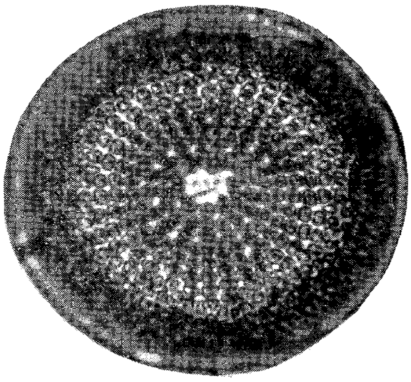

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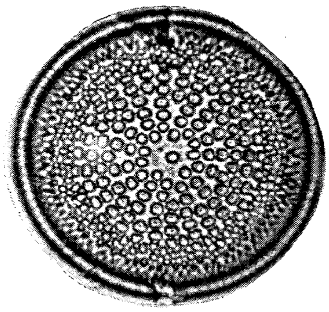

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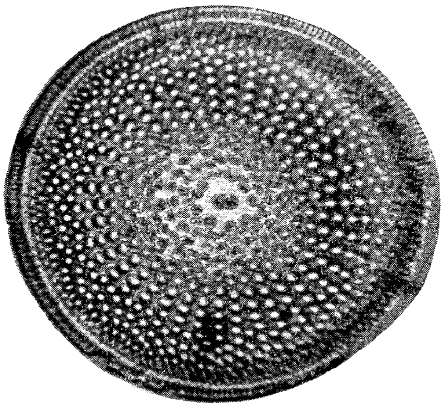

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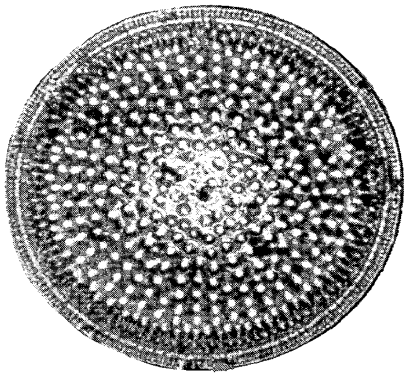

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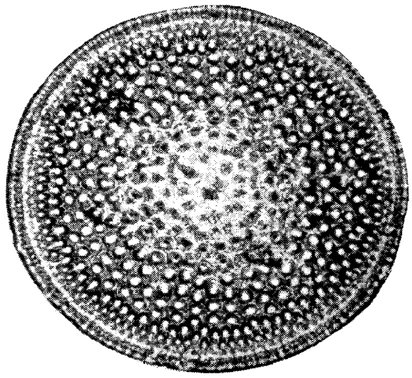


8b

PLATE VIII

Fig. 1. *Actinocyclus ingens* Ratt. IGPS coll. cat. no. 76610, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 53μ. $\times$ 800

Fig. 2. *Actinocyclus ingens* Ratt. IGPS coll. cat. no. 76611, from IGPS loc. no. Ao–12, Owaswa formation. Diameter 50.5μ. $\times$ 800

Fig. 3. *Actinocyclus ingens* Ratt. IGPS coll. cat. no. 76612, from IGPS loc. no. Ao–12, Owasawa formation. Diameter 40μ. $\times$ 800

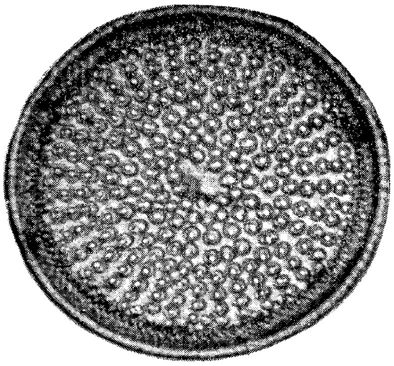
Figs. 4a, 4b. *Actinocyclus ingens* Ratt. IGPS coll. cat. no. 76613, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagwa formation. Diameter 40μ. $\times$ 800

Figs. 5a, 5b. *Actinocyclus tsugaruensis* Kanaya, n. sp. Holotype. IGPS coll. cat. no. 76615, from IGPS loc. no. Ao–9, Owasawa formation. Diameter 53μ. $\times$ 800

Figs. 6a, 6b. *Actinocyclus tsugaruensis* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76614, from IGPS loc. no. Ao–13, Owasawa formation. Diameter 53μ. $\times$ 800

Figs. 7a, 7b. *Actinocyclus tsugaruensis* Kanaya, n. ap. Paratype. IGPS coll. cat. no. 76616, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 75μ. A larger specimen. $\times$ 800

Fig. 8. *Actinocyclus tsugaruensis* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76617, from IGPS loc. no. Ao–9, Owasawa formation. Diameter 59.3μ. A transitional form to *Actinocyclus ingens* Ratt. $\times$ 800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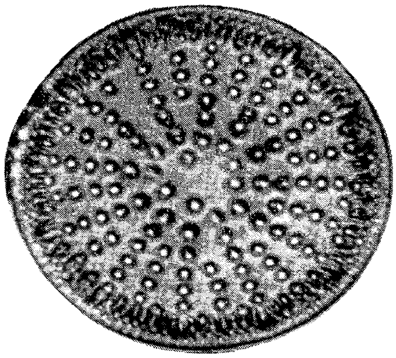
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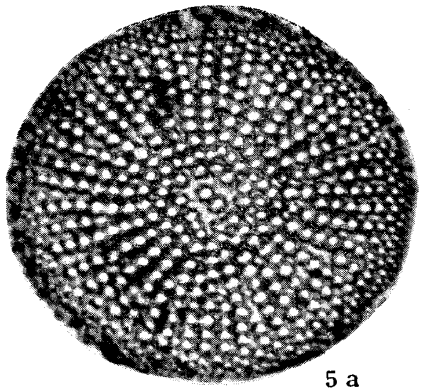
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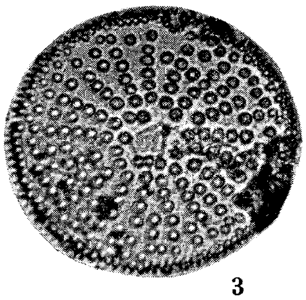
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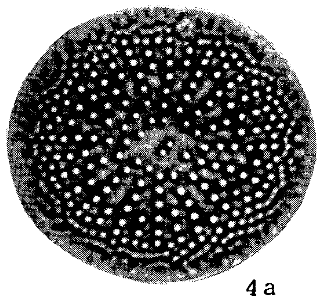
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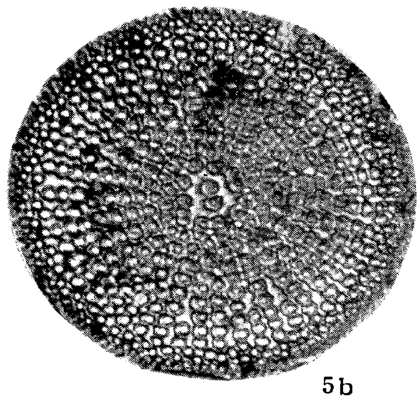
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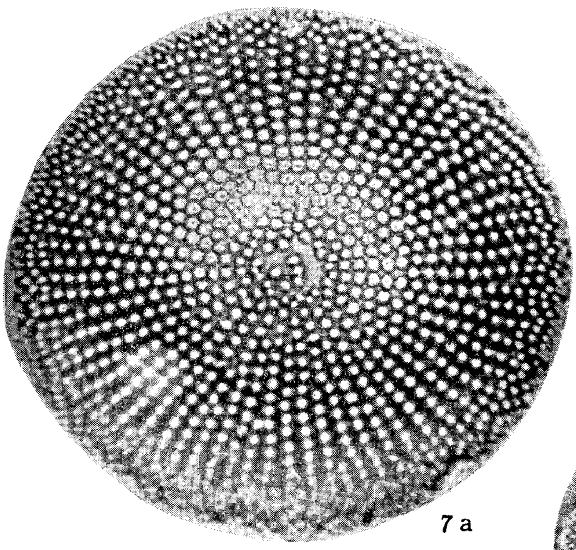
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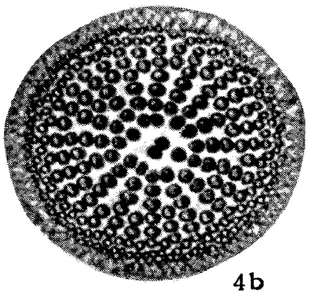
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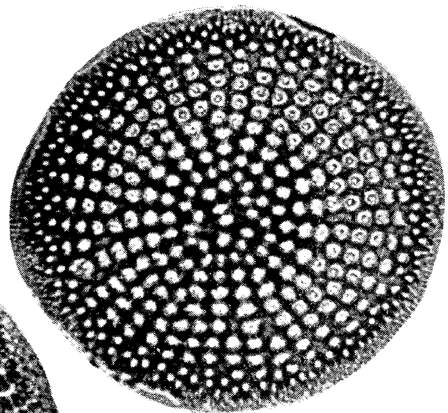
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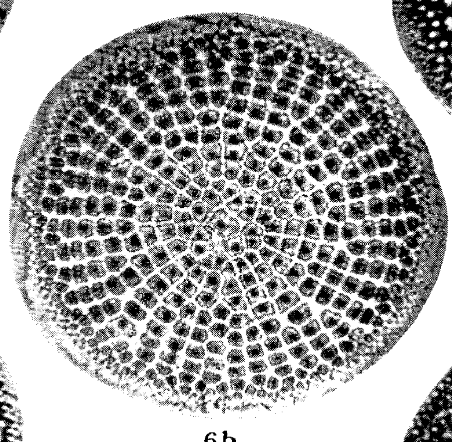
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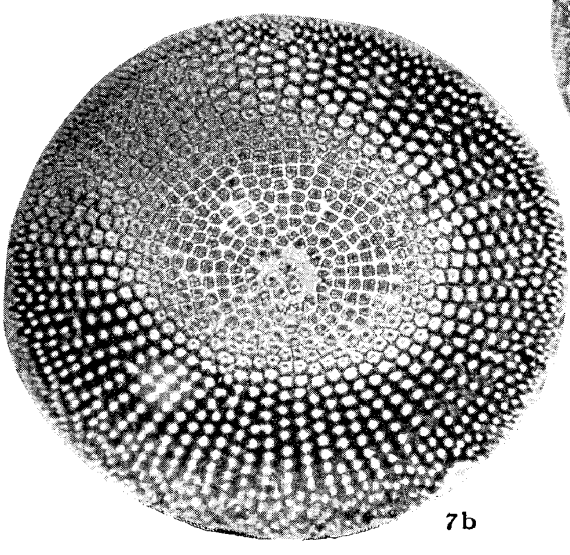
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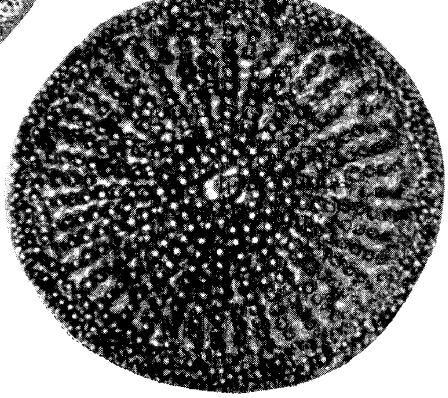
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PLATE IX

Fig. 1. *Rhizosolenia* sp. IGPS coll. cat. no. 76689, from IGPS loc. no. Ak–67, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of the broken specimen 61.5μ. × 800

Fig. 2. *Rhizosolenia* sp. IGPS coll. cat. no. 76690, from IGPS loc. no. Ak–53, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of the broken specimen 48μ. × 800

Fig. 3. *Rhizosolenia* sp. IGPS coll. cat. no. 76691, from IGPS loc. no. Ak–54, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of the broken specimen 114μ. × 640

Fig. 4. *Rhizosolenia* sp. IGPS coll. cat. no. 76692, from IGPS loc. no. Ao–12, Owasawa formation. Length of the broken specimen 69μ. × 800

Figs. 5a, 5b. *Triceratium* sp. α IGPS coll. cat. no. 76716, from IGPS loc. no. Ak–16, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of a side 52.5μ. × 1000

Fig. 6. *Triceratium* sp. β. IGPS coll. cat. no. 76717, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of a side 19.7μ. × 1000

Fig. 7. *Triceratium* sp. β. IGPS coll. cat. no. 76718, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of a side 24μ. × 1000

Fig. 8. *Grammatophora* sp. IGPS coll. cat. no. 76679, from IGPS loc. no. Ao–13, Owasawa formation. Length of apical axis 52.5μ. × 800

Fig. 9. *Grammatophora* sp. IGPS coll. cat. no. 76680, from IGPS loc. no. Ao–13, Owasawa formation. Length of apical axis 84μ. × 600

Fig. 10. *Grammatophora* sp. IGPS coll. cat. no. 76681, from IGPS loc. no. Ao–12, Owasawa formation. Length of apical axis 137μ. × 400

Figs. 11a, 11b. *Fragilaria hirosakiensis* Kanaya, n. sp. Holotype. IGPS coll. cat. no. 76674, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 38μ. × 1500

Fig. 12. *Fragilaria hirosakiensis* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76676, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 48μ. × 1500

Fig. 13. *Fragilaria hirosakiensis* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76675, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 31μ. × 1500

Fig. 14. *Fragilaria hirosakiensis* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76677, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 29μ. × 1500

Figs. 15a, 15b. *Fragilaria hirosakiensis* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76678, from IGPS loc. no. Ao–9, Owasawa formation. Lengh of apical axis 20μ. × 1500

Figs. 16a, 16b. *Rouxia Peragalli* Brun and Herib. IGPS coll. cat. no. 76693, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of apical axis 40μ. × 1000

Figs. 17a, 17b. *Rouxia Peragalli* Brun and Herib. IGPS coll. cat. no. 76694, from IGPS loc. no Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of apical axis 42μ. × 1000

Figs. 18a, 18b. *Rouxia Peragalli* Brun and Herib. IGPS coll. cat. no. 76695, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of apical axis 46μ. × 1000

Fig. 19. *Rutilaria epsilon* Grev. IGPS coll. cat. no. 76696, from IGPS loc. no. Ao–13, Owasawa formation. A broken specimen, 77.5μ in length. × 600

Fig. 20. *Thalassiothrix longissima* Cleve and Grun. IGPS coll. cat. no. 76715, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member, Onnagawa formation. A broken specimen, 130μ. in length. × 570

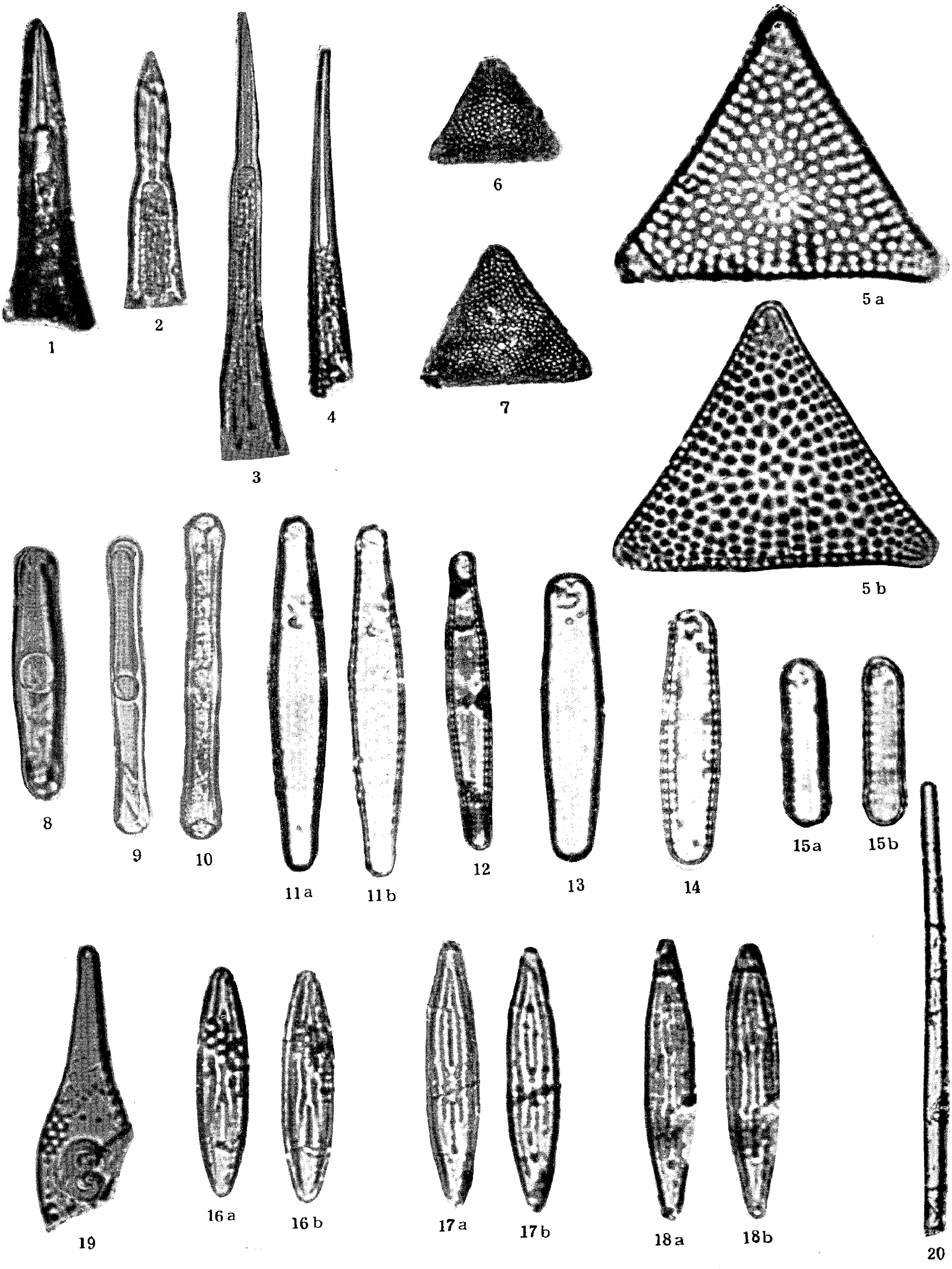
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PLATE X

Fig. 1. *Cocconeis antiqua* Brun and Temp. IGPS coll. cat. no. 76626, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of apical axis 70.5μ. × 800

Fig. 2. *Cocconeis antiqua* Brun and Temp. IGPS coll. cat. no. 76627, from IGPS loc. no. Ao–13, Owasawa formation. Length of apical axis 37.5μ. × 800

Fig. 3. *Cocconeis curvirotunda* Brun and Temp. IGPS coll. cat. no. 76628, from IGPS loc. no. Ak–64, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of transapical axis 69μ. A broken specimen. × 600

Figs. 4a, 4b. *Cocconeis formosa* Brun. IGPS coll. cat. no. 76629, from IGPS loc. no. Ak–59, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of apical axis 92μ. × 600

Fig. 5. *Cocconeis formosa* Brun. IGPS coll. cat. no. 76630, from IGPS loc. no. Ak–65, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of apical axis 30.8μ. Specimen tilted. × 800

Figs. 6a, 6b. *Cocconeis vitrea* Brun. IGPS coll. cat. no. 76631, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation. Length of apical axis 62.5μ. × 800

Fig. 7. *Denticula lauta* Bail. IGPS coll. cat. no. 76661, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 13.7μ. × 1500

Fig. 8. *Denticula lauta* Bail. IGPS coll. cat. no. 76662, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 15μ. Girdle view. × 1500

Fig. 9. *Denticula lauta* Bail. IGPS coll. cat. no. 76663, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 14μ. Girdle view. × 1500

Figs. 10a, 10b. *Denticula lauta* Bail. IGPS coll. cat. no. 76664, from IGPS loc. no. Ao–10, Owasawa formation. Length of apical axis 18.4μ. × 1500

Fig. 11. *Denticula lauta* Bail. IGPS coll. cat. no. 76665, from IGPS loc. no. Ao–12, Owasawa formation. Length of apical axis 27.5μ. Girdle view. × 1500

Fig. 12. *Denticula lauta* Bail. IGPS coll. cat. no. 76666, from IGPS loc. no. Ao–12, Owasawa formation. Length of apical axis 23μ. × 1500

Fig. 13. *Denticula lauta* Bail. IGPS coll. cat. no. 76667, from IGPS loc. no. Ao–12, Owasawa formation. Length of apical axis 32μ. Girdle view. × 1500

Figs. 14a, 14b. *Denticula lauta* Bail. IGPS coll. cat. no. 76668, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 43.4μ. × 1500

Figs. 15a, 15b. *Denticula lauta* Bail. IGPS coll. cat. no. 76728, from C.A.S. loc. no. 1068, Round Mt. Silt, California. Girdle view. Length of apical axis 15μ. × 1500

Fig. 16. *Denticula lauta* Bail. IGPS coll. cat. no. 76733, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 13.6μ. Valve view showing corroded surface. × 1500

Figs. 17a, 17b. *Denticula* ? sp. IGPS coll. cat. no. 76732, from IGPS loc. no. Ao–12, Owasawa formation. Length of apical axis 22.8μ. × 1500

Figs. 18a, 18b. *Denticula* ? sp. IGPS coll. cat. no. 76731, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 16μ. × 1500

Figs. 19a, 19b. *Denticula* ? sp. IGPS coll. cat. no. 76729, from loc no. Ao–9, Owasawa formation. Length of apical axis 16μ. × 1500

Figs. 20a, 20b. *Denticula* ? sp. IGPS coll. cat. no. 76730, from IGPS loc. no. Ao–9, Owasawa formation. Length of apical axis 16μ. × 1500

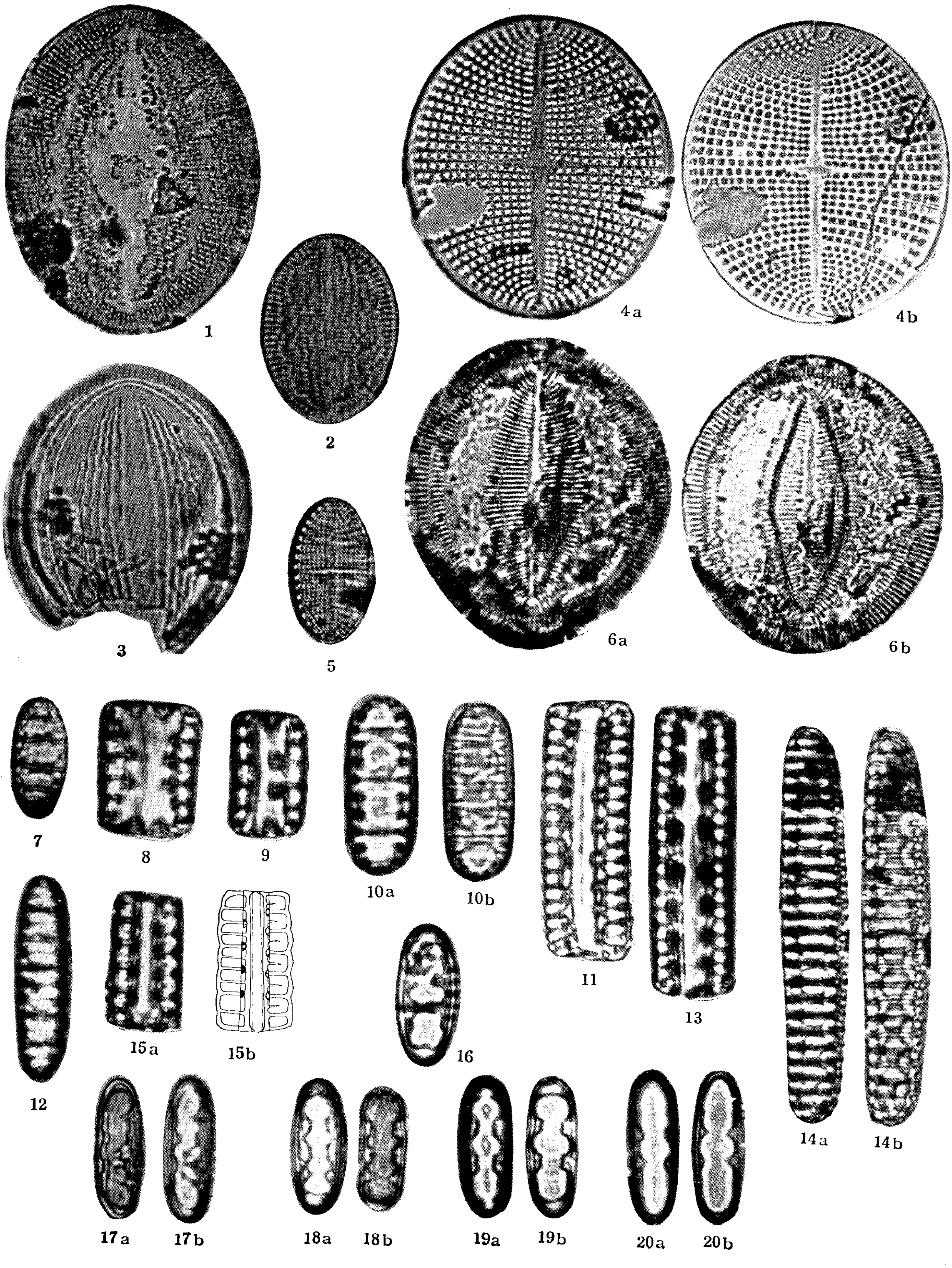
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PLATE XI

Fig. 1. *Dicladia capreolus* Ehr. IGPS coll. cat. no. 76669, from IGPS loc. no. Ak–63, Shinzan diatomaceous mudstone member, Onnagawa formation. Width of girdle view 18μ. × 1000

Fig. 2. *Dicladia capreolus* Ehr. IGPS coll. cat. no. 76670, from IGPS loc. no. Ao–9, Owasawa formation. Width of girdle view 18.3μ. × 1500

Figs. 3a, 3b. *Stephanogonia Hanzawae* Kanaya, n. sp. Holotype. IGPS coll. cat. no. 76697, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 30μ. Girdle view. × 1000

Figs. 4a, 4b. *Stephanogonia Hanzawae* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76698, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 34.4μ. Valve view. × 1000

Figs. 5a, 5b. *Stephanogonia Hanzawae* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76699, from IGPS loc, no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 16.4μ. Girdle view × 1000

Figs. 6a, 6b. *Stephanogonia Hanzawae* Kanaya, n. sp. Paratype. IGPS coll. cat. no. 76700, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 16.4μ. Girdle view. × 1000

Fig. 7. *Stephanogonia Hanazawae* Kanaya, n, sp. Paratype. IGPS coll. cat. no. 76701, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 13.7μ; two valves are in different pervalver length. Girdle view. × 1000

Figs. 8a, 8b. *Xanthiopyxis acrolopha* Forti. IGPS coll. cat. no. 76719, from IGPS loc. no. Ak–55, Shinzan diatomaceous mudstone member; Onnagawa formation. Valve view. Length of longer axis 50μ. × 1000

Fig. 9. *Xathiopyxis oblonga* Ehr. IGPS coll. cat. no. 76720, from IGPS loc. no. Ak–44–2, Hirasawa diatomaceous mudstone member, Onnagawa formation. Valve view. Length of the longer axis 18.4μ. × 1500

Fig. 10. *Xanthiopyxis oblonga* Ehr. IGPS coll. cat. no. 76721, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member, Onnagawa formation. A tilted specimen, focused at the basal edge of a valve. × 1500

Fig. 11. *Xanthiopyxis* sp. 1. IGPS coll. cat. no. 76722, from IGPS loc. no. Ao–12, Owasawa formation. Girdle view. Diameter 11.5μ. × 1500

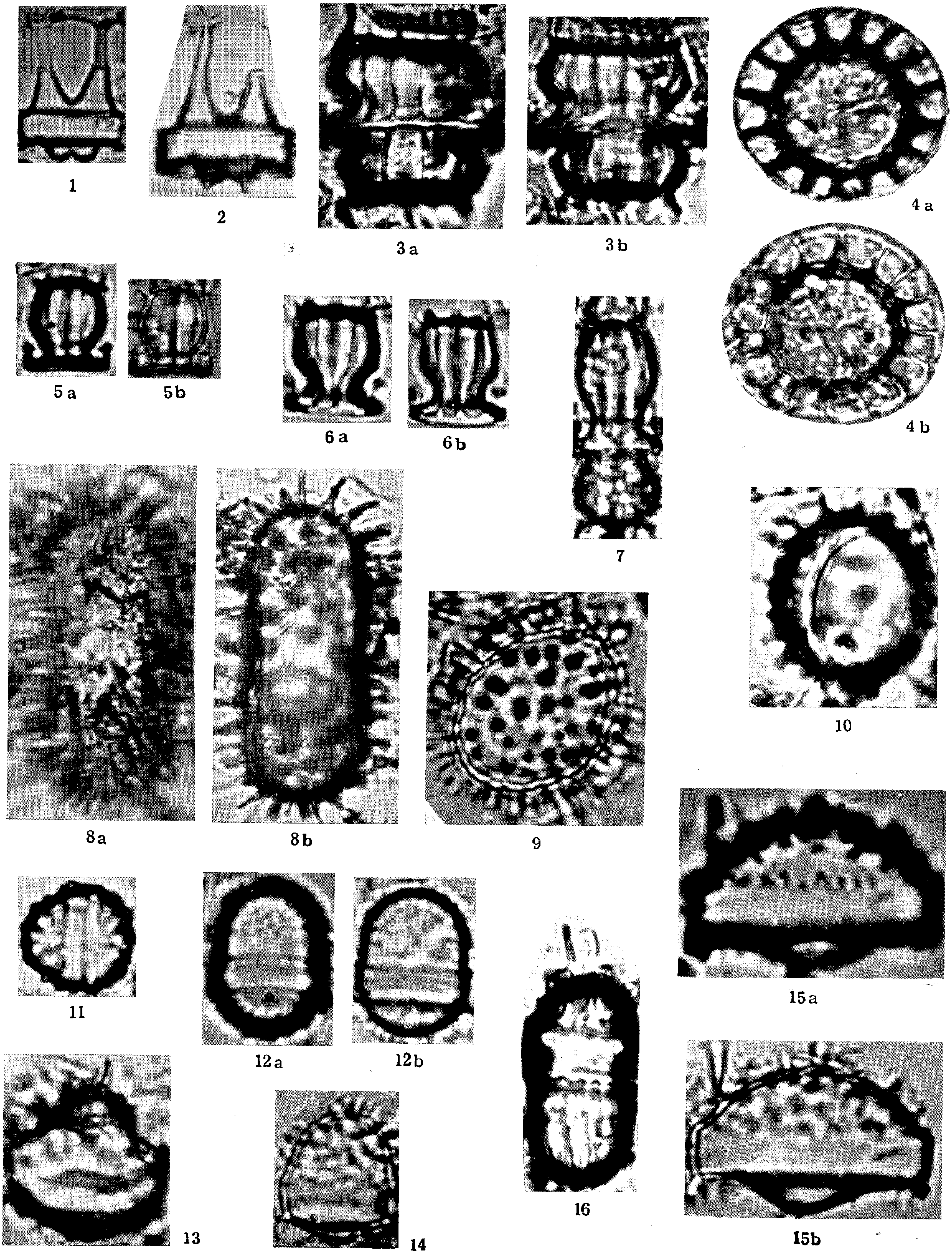
Figs. 12a, 12b. *Xanthiopyxis* sp. 2. IGPS coll. cat. no. 76723, from IGPS loc. no. Ak–48–5, Hirasawa diatomaceous mudstone member, Onnagawa formation. Diameter 16.4μ. Girdle view. × 1500

Fig. 13. *Xanthiopyxis* sp. 3. IGPS coll. cat, no. 76724, from IGPS loc. no. Ak-48–5, Hirasawa diatomaceous mudstone member, Onnagawa formaton. Diameter 16μ. × 1500

Fig. 14. *Xanthiopyxis* sp. 4. IGPS coll. cat. no. 76725, from IGPS loc. no. Ak–48–3, Hirasawa diatomaceous mudstone member. Onnagawa formation. Girdle view. × 1500

Figs. 15a, 15b. *Xanthiopyxis* sp. 5. IGPS coll. cat. no. 76726, from IGPS loc. no. Ak–48–1, Hirasawa diatomaceous mudstone member, Onnagawa formation. × 1500

Fig. 16. *Xanthiopyxis* sp. 6. IGPS coll. cat. no. 76734, from IGPS loc. no. Ak–57, Shinzan diatomaceous mudstone member, Onnagawa formation. Diameter 11.5μ. Girdle view. × 1500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